

HIGH-DEFINITION 3D ACQUISITION OF ARCHAEOLOGICAL OBJECTS AN OVERVIEW OF VARIOUS CHALLENGING PROJECTS ALL OVER THE WORLD

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Abstract:

Do you have any idea about the variety of challenging close-up range 3D scanning projects that are realised nowadays by archaeological specialists all over the world?

This paper describes several projects that have been realised successfully during the last years in different places all over the world, with various objectives as comparative and dimensional analysis, accessibility to data, replication, archival record and virtual reconstruction.

The paper will focus on archaeological projects with a wide range of scanning objects – from very small structures to huge immovable buildings – documented three-dimensionally under challenging conditions like changing weather, burning sunshine, freezing cold, high humidity, sand and thunder storms as well as dangerous animals and in different locations, sometimes many miles away from any modern civilization.

Follow us to interesting places all around the world and learn more about several challenging 3D projects in the field of archaeology that have been realised with our high-definition close-up range surface scanners!

1. INTRODUCTION

During the recent 20 years, high-definition three-dimensional (3D) surface scanners based on structured light or laser light section techniques, have been used for a wide range of applications in the technical and industrial sector. In the industrial application field, these scanners are especially used for measuring and inspection tasks.

Since approximately 10 years, these high-definition scanning systems are individually adapted to support with high resolution and accuracy the 3D digitisation in the application fields of art and culture. In this area, the scanners are e.g. employed for the 3D capturing of paintings and frescos (art work), sculptures, statues, busts and masks (objects of cultural value), petroglyphs and stone engravings (archaeology) or skulls, teeth and bones (anthropology, paleontology).

The final digital models of cultural objects created with the support of 3D scanning techniques are used for projects such as [8]:

- The documentation and archiving of art objects
- The virtual presentation in museums and in the internet
- The manufacturing and rapid prototyping of scaled copies and replicas
- The virtual reconstruction of art objects
- The scientific analysis of paleontological and archaeological findings
- The quantitative mapping of damages on sculptures and monuments
- The generation of identity cards and digital fingerprints
- The manufacturing of tailored transportation packages

2. STATE OF THE ART HIGH-DEFINITION SURFACE SCANNERS

State of the art topometrical high-definition 3D surface scanners, based on fringe projection techniques and optimized for the requirements of Arts and Cultural Heritage (see Figure 1), allow the 3-dimensional digitization of archaeological findings at highest resolution and accuracy. Moreover, the texture and / or colour of the object can be recorded, offering a one-to-one correspondence of 3D coordinate and color information. Important parameters of the system configuration such as field of view, triangulation angle and resolution may be defined by the user in accordance with the individual application requirements.



Figure 1: Topometrical High-Definition Surface Scanner smartSCAN3D-HE

State of the art systems are equipped with digital cameras of up to 5 MPixel, offering spatial resolutions for small fields of view down to 10 μm (according 2.400 dpi for flat surfaces) and depth resolutions of a few μm . Due to the high flexibility and mobility of these systems, they are highly suitable for an extensive variety of archaeological applications.

However, 3D surface scanners also have limitations. Most critical factor are the problems of triangulation techniques with undercuttings and deep holes as well as with shiny surfaces.

To overcome these restrictions, special system configurations and recording techniques are used, e.g. an asymmetrical two-camera setup which involves three triangulation angles in one sensor configuration or a modified High Dynamic Range acquisition technique [7], [8], [9]. The scanning results on shiny surfaces or objects with strong differences in reflectivity by making use of the modified High Dynamic Range acquisition can be seen in Figure 2.

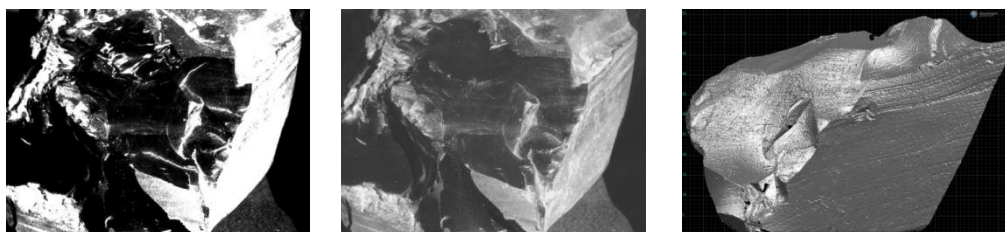


Figure 2: Digitization of obsidian with a modified High Dynamic Range technique (left: conventional 2D image - middle: 2D image recorded with HDR - right: visualization of recorded 3D data)

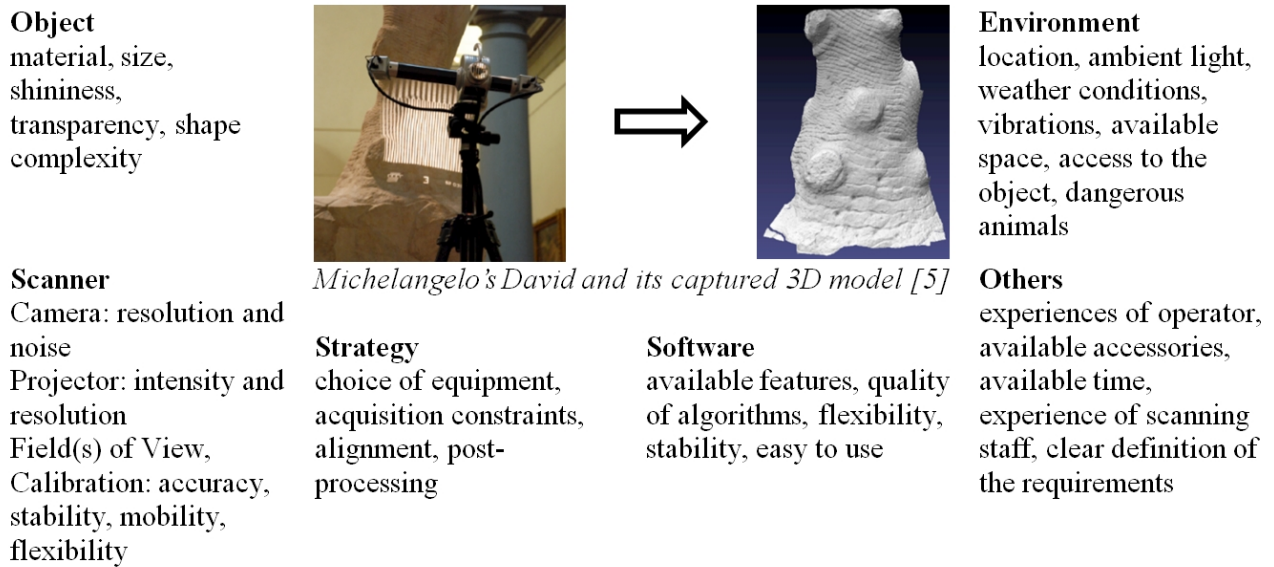
Table 1 shows some typical specifications of 3D surface scanning systems [12].

	<i>Typical specification ranges</i>	<i>Example of a commercial 3D scanner</i>
<i>Camera</i>	CCD/CMOS device, color or black/white	CCD, color
<i>Digitization</i>	0.3 to 6 MPixel	2 x 5 MPixel
<i>Light source</i>	Laser, LED, halogen or discharge lamps	250 W halogen lamp
<i>Field of View</i>	about 20 mm to 2 m	300 mm
<i>Data acquisition time</i>	0.5 sec to minute per single scan	1 sec / scan
<i>Triangulation angle</i>	5 to 40 degree	30/20/10 degree
<i>inter-sampling distance</i>	5 μm to mm	100 μm
<i>X/Y resolution</i>	10 μm to mm	150 μm
<i>Depth resolution</i>	2 μm to 200 μm	10 μm
<i>Accuracy</i>	5 μm to mm	15 μm (VDI/VDE 2634/2)

Table 1: Typical specifications of 3D surface scanners

3. CHALLENGES

3D scanning projects – in the lab or in the field – always have to face some challenges that have to be managed on the way from capturing object data up to exporting a final model of it. The following overview will name some possible challenges scanning staff has to deal with. As can be seen in Figure 3, the measuring object itself as well as the scanning environment can be equally challenging; also the scanner, the scanning strategy, the used software and other factors may be sources of problems.



Michelangelo's David and its captured 3D model [5]

Figure 3: Influencing factors for 3D surface scanning

4. PRESENTATION OF DIFFERENT 3D SCANNING PROJECTS

4.1 3D White-light scanning of the historical huts of Scott and Shackleton in Antarctica

The New Zealand-based company Geometria, an advisory and research services provider in the fields of archaeology and cultural heritage management, joined in 2010 a long-term multidisciplinary study (K021 project) where, amongst other things, the effects of biological and non-biological deterioration on the Heroic Era huts of the two famous British polar explorers Robert Falcon Scott and Ernest Shackleton, on Ross Island are investigated.

During January 2011, members of Geometria and the University of Waikato (New Zealand) made their way to Antarctica to conduct a comprehensive three-dimensional white-light and laser scanning project of Scott's huts at Hut Point and Cape Evans (see

Figure 4) as well as Shackleton's hut at Cape Royds.

The wooden huts, pre-fabricated in England and then assembled in Antarctica during this Heroic Era of Antarctic exploration, represent one of the great periods of human endurance and endeavour. The resulting scan data will not only support multi-disciplinary studies but also help to develop interpretative models for broader public consumption.



Figure 4: Scott's Terra Nova Hut at Cape Evans (© New Zealand Antarctic Heritage Trust)

Although these huts, a memorable legacy of this famous British Antarctic Expedition Terra Nova (1910 - 1913), have been exposed to the elements in one of the most inhospitable environments on earth for over a century, they are preserved in amazingly good condition. Because of their remoteness, the huts have not been subjected to major human impact since their abandonment about 100 years ago, except for recent scientific investigations of deterioration and conservation of the buildings and their contents. The significance of these sites with regard to their cultural heritage as well as their inaccessibility requires the site's digital recording, modelling and remote interpretation for detailed scientific studies.

Breuckmann's structured white-light scanner smartSCAN^{3D}-HE was chosen to be best up for this 3D scanning challenge in harsh Antarctic conditions, because it offers a feasible solution to deliver consistent and dependable performance as well as to generate highly precise scan data. The scanner was used in freezing temperatures varying from -2°C to -12°C, but this did not have any impact on the system itself or the quality of the generated scan data: The reliably and stable working smartSCAN^{3D}-HE is an excellent system for harsh field work.

Given the project's limited time frame of only two weeks, the comprehensive and therefore time-consuming 3D data acquisition of a measuring project of this size and volume is a demanding affair. Nevertheless, the expedition members managed to digitise as much as possible both of the huts' exterior structures as well as various artefacts found inside the abandoned huts (see Figure 5).



Figure 5: left: Blocking ambient light to allow exterior structured light scanning
right: 3D Scanning of Terra Nova interior artifacts (© Geometria)

Due to the interfering influence of ambient light, scanning outside the huts posed the biggest challenge: In the Antarctic summer with 24 hours of daylight, the light comes in from all angles and, to add to the difficulty, is reflected by the snow. Any scanning work on the external surfaces of the huts had therefore to be carried out under cover of large makeshift light protection shields which were not always available or easily fabricated.

For future scanning projects in Antarctica, the team plans to work with pre-constructed collapsible light shields rather than improvising with on-site solutions made from tarpaulins and bed linen (see Figure 5).

Figure 6 shows some of the 3D scanning results.



Figure 6: Visualization of various 3D scan data of Terra Nova interior artifacts captured by Geometria

For further reading please see [1], [2], [3].

4.2 The Mongolian Deer Stone Project

The American-Mongolian Deer Stone Project [4], [6], [10] is a research project of Mongolian Archaeologists, the Smithsonian Institution, (e.g. Arctic Studies Center, Smithsonian Museum Conservation Institute - MCI), Accurex Dimensional Measurement, Inc., and the Breuckmann GmbH. The DSP project started in 2001, including research activities side-by-side with Mongolians in the province of Hovsgol Aimag in Northern Mongolia. In 2005, MCI conservators expanded the scope to include documentation of carved stone monoliths dating to 1st – 2nd millennium BC and earlier by the use of a 3D scanning system. After the first successful trip in 2006, a Breuckmann 3D scanner played a key role for research in Mongolia again in 2007.



Figure 7: left: Khushuugiin Devseg deer stone, right: Drawing of Uskiin Uver deer stone

The documentation program complements efforts to promote the understanding and preservation of the deer stones. These significant monuments are not well recorded and at on-going risk of damage from environmental and human causes. The project's 3D imaging component is of particular importance, as it allows precise and high-resolution metrological information, describing the surface geometry of a 3D object. Each stone is captured without touching the original. In conjunction with other documentation materials, the digital records are to be used for base-line archival records, as well as research and education.

For scanning, a Breuckmann triTOS structured light system with 1.4 Megapixel cameras, owned by the Smithsonian Institution, was used. This system is designed to meet the special requirements in art and cultural heritage, preservation of historical monuments and archeology. It delivers high resolution and accuracy as well as a colour image of the surface. To make scanning in the Mongolian steppe as easy as possible, a Hewlett-Packard Pentium IV laptop computer was used to run the system. The computer and scanner were powered in the field by a Honda EU1000i generator developed specifically for the use with precision equipment.

From Ulaanbaatar the whole team (including amongst others archeologists, conservators and scanning experts) started a four-day trip with all-terrain vehicles across country and on dirt tracks to Hovsgol Aimag, about 600 miles north of Ulaanbaatar where the scanning should take place.

Driving at a good pace across stones and dirt roads, the team, and of course the scanning equipment in the trunk of the van, were given "a good shake", to quote a team member. Other highlights of the trip to the north, just to name a few challenges included crossing decayed timber bridges with more than one tonne of weight in all-terrain vehicles along with important equipment on board over torrential rivers; driving through some rivers, when no bridges were available; and getting stuck in the mud, and having to push the car out.

Finally arriving at Hovsgol Aimag, the team was in good condition, although with some small bruises. In contrast, the scanning system with its flight case, was in a much better condition! Depending on weather conditions and schedules that needed to be synchronized with the archeological team, 3D digitizing of the deer stones took place at day- or nighttime.

A structured light scanning system, consisting of one camera and projection unit, is somewhat sensitive to light conditions, which can affect the contrast of the light patterns projected on the object and – consequentially - the scan quality.

Hence, when daytime scanning was necessary, the deer stones and triTOS sensor needed to be covered in order to reduce the ambient light. Shelters large enough to accommodate the working distance between the tripod and surface to be digitized had to be constructed (see Figure 8). To fulfill these demanding tasks, the Mongolian drivers covered long distances to borrow huge wooden panels from animal corrals. These along with canvas were dropped on the panel construction to provide shade shelters.

While the daytime temperatures outside the shelter were very pleasant (15 - 20°C), the temperatures in the shelter rose very fast. After only a few minutes, the temperature was about 50°C. Heavy rains and strong

winds caught the team off guard in the scanning shelters. The tent-like construction threatened to be overturned, rain intruded into the tent and the generator outside the shelter got wet. Of course, the team had to stop scanning, pack up everything and wait in the vans to start working again. This was by far not the only occasion when they had to deal with rapidly changing measurement conditions.

Because the team's second destination was farther South, the outside temperatures were higher (but still hard to bear) and the weather was more stable. Due to this, nighttime scanning became possible (see Figure 8).



Figure 8: Day- and nighttime scanning of the deer stones

Night scanning proved to be the most effective arrangement, obviating the need for a shelter and providing ideal light-contrast conditions to produce excellent data.

While scanning in shelters during daylight made the team sweat, night scanning in the amazing isolated steppe of Mongolia made them shiver. The temperatures at night were about 0°C. Sitting outside on a folding chair at this temperatures and only moving fingers to control the mouse of the laptop the whole night, or only changing the tripod's position a little bit every few minutes to capture a new patch, could bring one to a physical limit if they don't wear long johns, warm trousers, a jacket and particularly thick gloves.

The members of the expedition were especially impressed by the system's reliability after an adventurous transport for more than 1,200 miles over rough and smooth roads in all-terrain vehicles. With a laptop, an electric power generator and a simple tripod, the system demonstrated its applicability for measurements in the field. Neither variations in temperatures, between 0°C at night and 50°C in the day, nor the fine dust, blown by the wind through the Mongolian steppe, did affect the quality of the 3D scans [4], [6], [10].

4.3 Preservation of extensive Bas-Reliefs in the Khmer Temple of Banteay Chhmar (Cambodia) by 3D Scanning

One of the largest known Khmer temples including those in Angkor and also one of the largest temples in the world occupying about 9 square kilometres, is the little-known and rarely visited temple complex of Banteay Chhmar (see Figure 9). It is located in a deep jungle in the north-west of Cambodia close to the Thai border.

Not only by threats like climate or vegetation, but also acid rain or structural instabilities, vandalism and severe looting, the temple complex has sustained very serious destruction. Only about 20% of the main structures are still-standing. Most of these walls need yet to be stabilized.

The necessity to preserve the valuable carvings and structures built the basis of a four months 3D scanning campaign in Cambodia conducted by the Interdisciplinary Center for Scientific Computing (IWR) of the Heidelberg University and the Global Heritage Fund [11].



Figure 9: left, middle: The 12th century Khmer Temple in Banteay Chhmar, Cambodia, right: The Avalokeshvara bas-relief (© Global Heritage Fund)

Because of the critical need for conservation, master planning and increased protection, the scanning team decided for a rapid and digital acquisition workflow to preserve the famous bas-reliefs: They make use of 3D scanning technique which works contactless and delivers high-resolution 3D data within a short time. After extensive tests of different 3D scanning systems from various vendors the IWR team decided on a Breuckmann smartSCAN^{3D}-HE for the 3D capturing of several square meters of a still-standing Avalokeshvara bas-relief and several hundreds of fallen stones.

Because the eastern wall of the temple complex is about to collapse and needs foundation, parts of the wall were dismantled. The first venture of the scanning team was to set a start-up for a virtual reconstruction by scanning about 130 of those dismantled stones. The second project part was to document the well-known still-standing bas-relief featuring a buddhistic multi-armed bodhisattva (names Avalokeshvara) with a height of 4 m and a length of 7 m (see Figure 9).

Because the scanner is based on structured light, it requires a dark environment to operate at its best. So preferably most of the actual scanning should be done at night or indoors. During the campaign in Banteay Chhmar however, it was not possible to pursue this approach because of dangerous animals in the jungle around the temple site during night time. To cope with the fact that the 3D data acquisition had to take place during broad daylight, a workaround was to be found. For the first objective – gaining 3D data of separate stones – a scanning tent was built especially for this task. This closed tent however, did have the disadvantage of heating up while standing in bright sunlight. For the team members, it was as difficult working in this heat as it was for the notebook in use. Only the smartSCAN^{3D}-HE worked fine although the inner temperature of the scanner went up to about 62°C. For the second objective – recording of the Avalokeshvaras on the western wall – more than 1,500 scans were needed to cover the whole structure. The working environment itself was very much influenced by the actual condition of the surrounding including ground surface and height of the structure. Fallen stone blocks made it hard to place the 3D scanner in the right working distance to the wall. As the aforementioned tent could not be used here, the sunlight was dimmed out by using multi-purpose plastic covers. In order to be able to also reach the upper part, scaffolding was installed.

To cover both of the still-standing Avalokeshvaras and also their back, it took about 4 weeks and 1,539 scans. The final 3D model will presumably contain about 1,800 million vertices and 3,600 million faces. The single stones in comparison had been scanned in about 3.5 weeks taking 8 - 20 scans for a mean stone possessing about 7 million vertices and 13.6 million faces on the average. Because processing of this big amount of acquired scan data is time consuming, it is still in process and will be challenging as well [11].

5. SUMMARY

As we have demonstrated, high-definition 3D data acquisition of various archaeological objects is often associated with challenging conditions. The 3D data and 3D models generated by these scans are mainly used for documentation, archiving, virtual presentation, scientific analysis and rapid prototyping.

We also have discussed how scanning teams can meet the principal limitations of topometrical 3D scanners as well as dependencies and influences of different parameters, such as environmental conditions, object material, scanning strategy by working with auxiliary materials. In addition, we pointed out the importance of a highly reliable 3D scanning system to guarantee the success of often complex and time consuming expeditions related to a specific archaeological project.

Effort and costs for recording high-definition 3D data of objects are still higher than those for obtaining high-resolution 2D pictures. However, it can be expected, that they will continuously decrease within the next years. The experiences of those challenging projects, which have been reported in this paper, will support in developing even more advanced 3D scanning technologies. And they will also help other users with planning and conducting similar projects in the future with less effort and costs.

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REFERENCES

- [1] Antarctic Heritage Trust, Conservation Report: Shackleton's Hut British Antarctic Expedition 1907-1909, Christchurch, 2003
- [2] Antarctic Heritage Trust, Conservation Plan: Discovery Hut, Hut Point, Christchurch, 2004
- [3] Antarctic Heritage Trust, Conservation Plan: Scott's Hut, Cape Evans, Christchurch, 2004
- [4] Bathow, Christiane; Wachowiak, M.. "3D scanning in truly remote areas." *The Journal of the CMSC* Vol.3 (2008): 4-9.
- [5] Bathow, Christiane et al., "Documenting and Monitoring Small Fractures on Michelangelo's David", Paper presented at the 38th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Granada, Spain, April 6-9, 2010.
- [6] Beaubien, R. et al., "Documentation of Mongolia's Deer Stones", Project Summaries 2006: Museum Conservation Institute, Smithsonian Institution, Suitland, Maryland, Mar. 1, 2007: 86.
- [7] Breuckmann, Bernd et al., "High Definition 3-dimensional Scanning and printing Technologies in Arts and Cultural Heritage, Archaeology and Palaeontology", Paper presented at the conference Electronic Visualisation and the Arts (EVA), Berlin, Germany, November 7-9, 2007: 95-100.
- [8] Breuckmann, Bernd; Végvári, Zsófia. "High Definition 3D-Surface Scanning and Applications in Arts and Cultural Heritage", Paper presented at the 36th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Budapest, Hungary, April 2-6, 2008.
- [9] Breuckmann, Bernd et al., "High Definition 3D-Surface Scanning in Arts and Cultural Heritage", Paper presented at the 37th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Budapest, Hungary, March 22-26, 2009.
- [10] Fitzhugh, William W.; Bayarsaikhan, J.. "American-Mongolian Deer Stone Project: Field Report 2007". published by Arctic Studies Center, National Museum of Natural History, Smithsonian Institution, Washigton D.C.. 2008.
- [11] Schäfer, Anja et al., "Visualization and Documentation of Weathered Bas-Reliefs using Close-Range 3D-Scanners", in: Proceedings of the Seventh International Conference on Science and Technology in Archaeology and Conservation and the Workshop on Documentation and Conservation of Stone deterioration in Heritage Places, Petra, Jordan, December 7-12, 2010.
- [12] Scopingno, Roberto et al., "Accuracy Characterization and Verification for High Definition 3D Scanners", Paper presented at the 11th VAST International Symposium on Virtual Reality, Archaeology and Cultural, Paris, France, September 21-24, 2010.