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3D Scanning in Truly Remote Areas

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Abstract

Do you think you have a challenging environment for metrology?

This paper describes the Smithsonian Institution's expedition to Mongolia in the summer of 2007, with a structured light system to collect 3D scan data of stone monoliths from the Bronze Age. This expedition was characterized by travelling in Russian all-terrain vehicles for more than 1200 miles across country and on dirt tracks, passing through rivers without bridges, changing weather conditions, extreme temperature differences each day, sand- and thunder storms, being many miles from any modern civilization, and scanning under the stars.

Keywords: Deer Stone Project, tri*TOS*, cultural heritage, structured light, 3D scanning

1. Introduction

The American-Mongolian Deer Stone Project (DSP) 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. Beginning in 2006, a Breuckmann 3D scanner was used. After a successful first trip in 2006, a Breuckmann system had a key role for research in Mongolia again in 2007. The 2007 on-site project group included Harriet F. Beaubien, Dr. Paula DePriest and Dr. William W. Fitzhugh from Smithsonian Institution, his team, as well as Mongolian archeologists, and Christiane Bathow (Breuckmann GmbH).

The documentation program complements efforts to promote the understanding and preservation of the deer stones. These are significant monuments, which are not well recorded, and are at on-going risk of damage from environmental and human causes.

The 3D imaging component is of particular importance, as it allows precise and high-resolution metrological information, describing the surface geometry of a 3D object, and is captured without touching the original. In conjunction with other documentation, the digital records are to be used for base-line archival records, as well as research and education.

2. Introducing Deer Stones

Deer stones are Mongolian ancient megaliths that are carved with symbols like flying deer. In addition to that, they may also include a circle at the top, a face, stylized daggers, a belt at the bottom, tools, and other ornaments. The purpose of these deer stones, which have a height between 0,5m and approximately 4m, and their creators are unknown. Over 550 deer stones have been identified in Mongolia's grassy steppe region. They occur singularly, in small groups, or they may also be concentrated in larger groupings. Bronze Age nomads presumably erected deer stones approximately 3000 years ago.

Fig.1 Avtiin deer stone
[Bathow, 11 June 2007]

Fig.2 Khushuugiin Devseg deer stone [Bathow, 18 June 2007]

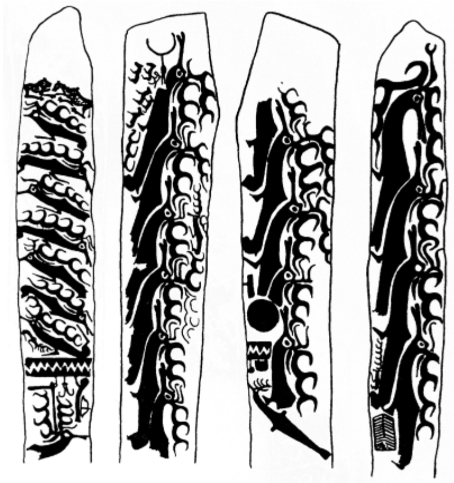

Fig.3 Drawing of Uskiin Uver deer stone

3. Scanning System and Equipment

In 2007, a Breuckmann tri*TOS* structure-coded light system was used for the scanning. 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 color image of the surface.

Fig.4 tri*TOS* scanner [Breuckmann]

The tri*TOS* consists of a sensor bar with a projector and a color camera (1384x1036 pixel) mounted on a tripod, a calibration plate, and a controller. All were safely transported in a custom-made flight case. The lenses of the camera and projector are interchangeable to give varying fields of view. In this case, lenses for field of view (FOV) 675 mm were used, which allow digitizing patches with a diagonal of 67 cm [26,5 inches] each.

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 use with precision equipment. The tri*TOS* system is a topometric system that makes use of the principle of optical triangulation in combination with structured illumination. The 3D sensor is based on the Miniature Projection Technique (MPT), and utilizes a combination of Gray code and phase shift technique, which guarantees an unambiguous determination of recorded 3D data. Patterns of well defined periodic fringes are projected onto the object, and recorded by a high-resolution camera positioned at a defined angle. Subsequently, the acquired images are further processed within a powerful image processing system.

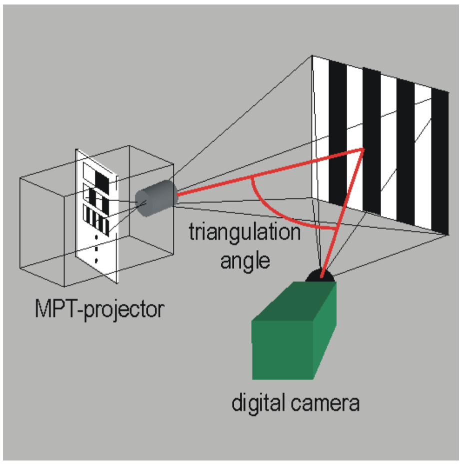

Fig.5 Mode of operation of a topometric sensor [Breuckmann]

4. Travelling through Mongolia

The scanning team, Harriet F. Beaubien, (MCI Senior Objects Conservator), and Christiane Bathow, (3D metrologist from Breuckmann GmbH), arrived in Mongolia on June 5th, 2007, meeting up with other members from the DSP team in Ulaanbaatar.
From Ulaanbaatar the whole team, about 20 people (archeologists, conservators, scanning experts, an art professor, a couple of students, a guide, and a cook) started a four day trip with all-terrain vehicles across country and on dirt tracks to Hovsgol Aimag, about 600 miles north of Ulaanbaatar.
The trip started with eight people per vehicle at temperatures of about 85° F. Naturally, the first hundred miles through the dusty steppe were very exhausting for everyone, not only the drivers. 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. Other highlights of the trip to the north 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. At the end, the team arrived in good condition at Hovsgol Aimag, although with some small bruises. The scanning system, packed in the flight case, came through the trip in much better condition .

Fig.6 Driving trough the Mongolian steppe [Bathow, 6 June 2007]

Fig.7 Pulling the van on the other side of the river [Bathow, 16 June 2007]

5. 3D Scanning

The team's primary objectives during the 2007 field season were to document deer stones at sites that the DSP would be surveying and excavating in Hovsgol Aimag, especially the northern Darkhad Valley region; and to complete the documentation of deer stones from the site of Ushkiin Uver, by scanning two fragments belonging to a deer stone, currently stored in the Hovsgol Museum collection. Over a three-week period, complete high-resolution 3D digital records were produced for 15 deer stones from six locations, including the Hovsgol Museum.
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 night-time.
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 affects the scan quality.
Hence, when daytime scanning was necessary, (e.g. in Avtiin and Hort Uzuur, Hovsgol Museum), the deer stones and tri*TOS* 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 scanned had to be constructed. Therefore, the Mongolian drivers covered big distances to borrow huge wooden panels from animal corrals. These along with canvas were dropped on the panel construction to provide shade shelters.

Fig.8 Avtiin deer stone w/shelter setup for day-time scanning [Bathow, 12 June 2007]

While the daytime temperatures outside the shelter were very pleasant (50-70° F), the temperatures in the shelter rose very fast. After only a few minutes, the temperature was about 122° F. Due to the limited space in the shelters, the scanning of the stone monoliths took a while. Depending on the size of the deer stones, scanning could take between 0,5 to 2 hours. After setting up and calibrating the system the scanning team was already sweating, and felt as if they were in a sauna.

Fig.9 Day-time scanning in shelter [Beaubien, 12 June 2007]

In the northern Darkhad Valley beyond Tsagaanuur, (very close to Siberia); the team's first destination for daytime scanning and archeological research; the weather was changing very often. Heavy rains and strong winds caught the team off guard in the scanning shelters. The tent-like construction threatened to be overturned, rain got in the tent, and of course the generator outside the shelter got wet. Of course, when this happened Beaubien and Bathow had to stop scanning, pack up everything, and wait in the vans to start working again. After such heavy rains the outside temperature fell rapidly. Therefore, they often had to deal with changing measurement conditions.

Fig.10 Change in the weather pattern in Darkhad Valley [Bathow, 12 June 2007]

After five days of archeological excavating and scanning six deer stones, the team left the Darkhad Valley to start further archeological research and digitizing of stone monoliths at the deer stone site of Khushuugiin Devseg, on a plateau of Lake Erkhel, a couple of hundred miles away from the first destination. Because the location of team’s second destination was farther South, the outside temperatures were higher, and the weather was more stable. Due to this, nighttime scanning became possible. 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. This approach was used to scan the deer stones at the sites of Khushuugiin Devseg, (base camp), and Khyadag, which was easy to access by van, (driving time one hour). Furthermore, the stone monoliths of this region have a larger height than the stones the scanning team, Bathow and Beaubien, digitalized in the far north. The nearly 3-meter deer stone in the Khyadag West Group would have been extremely difficult to shade otherwise.

In the five days they stayed in this area, the scanning team digitalized seven deer stones, two in the base camp and five monoliths in Khyadag East and West.

The summer sunset occurs fairly late, so the team set up the system around 10 pm, and started with a calibration, which took about 5 minutes. System calibration was always at the beginning of each session, and recalibration was only done if environmental conditions changed dramatically.

Fig.11 System calibration (foreground) and cleaning monoliths (behind calibration plate) with bamboo skewers and toothbrushes to remove accretions [Bathow, 19 June 2007]

The scanning started at 11 pm, then the team scanned a couple of stones per night up to 3 am, or even as late as 4am, under a breathtakingly starry sky.

While scanning in shelters during daylight made the team sweat, night scanning in the amazing isolated steppe of Mongolia made the team shiver. The temperatures at night were about 32° F. Being outside for a short time at this temperature isn´t a problem, but sitting on a folding chair, and only moving fingers to control the mouse of the laptop the whole night, or only moving the tripod a little bit every few minutes to capture a new patch, would bring one to a physical limit if they don't wear long johns, warm trousers, a jacket, and particularly thick gloves.

Fig.12 Khushuugiin Devseg deer stone being scanned at night [Beaubien, 21 June 2007]

While based in the Lake Erkhel region, the scanning team returned for one day to the Hovsgol Museum in Muren to scan the fragments of a deer stone from the Ushkiin Uver site, which are now considered part of the museum collection.

The fragments were stored in a secure metal cage structure in the backyard of the original museum building. After receiving the scanning permission, they scanned two stone fragments in the metal cage, covered with canvas.

This scanning took the team 2.5 hours, in a tight cage like a captive animal. In fact, before the cage was used for storage, it had belonged to a zoo in the backyard of the museum that showed typical Mongolian animals.

For the team, this and scanning under the stars are the most unforgettable scanning locations.

Fig.13 Covering a metal cage with canvas for day-time scanning in Hovsgol Museum [Beaubien, 19 June 2007]

Fig.14 Setting up the system in a metal cage [Beaubien, 19 June 2007]

6. Data Processing

The scan data of all digitalized deer stones were stored on the HP laptop computer, and a backup copy on an external hard drive. Depending on the amount of raw data per scanned deer stone, some of the carved monoliths were directly processed in Mongolia. The taller stones, which consist of 50 to 70 single scans were processed by Basiliki Vicky Karas, (Objects Conservator/3-D Scanning Specialist), at the Smithsonian Museum Conservation Institute after the expedition.

The following processing steps were carried out from the raw point clouds to 3D visualization.

- Registration (Alignment)
    - Pairwise registration
    - Global registration
- Point cloud editing
- Merging
- Hole Filling
- Visualizing

For creating a STL or PLY-file of the scan raw data, all captured single scans of a deer stone have to be aligned in the first step, using Breuckmann's Optocat 2006 system software. This alignment was done by comparison of the 3D geometry of the digitized object without using any additional markers. After pairwise registration of all single scans was made, a machine-aided global alignment was done.

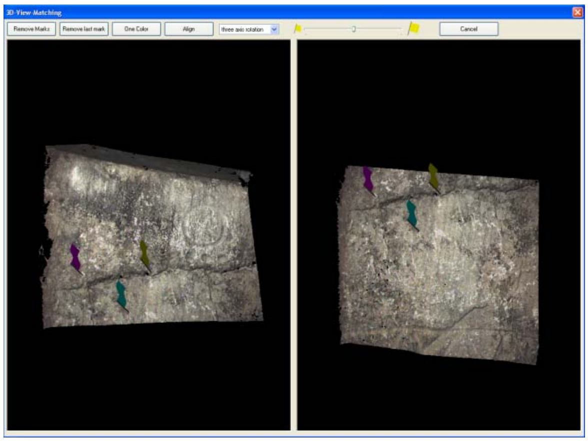

Fig.15 Pairwise alignment of adjacent scans

Because the scanning system records the point cloud (XYZ) and color values (RGB) together, the color information is registered exactly with its corresponding 3D point. To achieve a good color transition between neighboring scans, which are captured from different scanning positions with different ambient light influences, editing the point clouds (for example, deleting points in overlap-areas) is recommended.
After finishing these processing steps, the point cloud, consisting of several single scans, must be merged. With this step the raw data point cloud is converted into a PLY file.

Fig.16 3D visualization of the PLY file of an Ushkiin Uver deer stone fragment

Fig.17 Ushkiin Uver deer stone fragment as picture

The PLY format is designed to store 3D data with a variety of properties, such as color information, surface normals, and texture coordinates. These features allow the front and back sides of the surface data's polygonal mesh to have different properties.

After merging the single scan data into a complete object, further processing steps were completed, such as filling holes in the mesh. This was accomplished by Vicky Karas using Rapidform XOS (3D graphic software). The software allows the operator to select the particular holes to fill, and create a full extrapolating curvature from the data mesh surrounding the hole. The fills are displayed as a uniform mesh (in mesh view), or as a smooth patch for larger fills (in solid view), so that fills are always detectable. The fully processed data files are saved as new PLY file, which can be exported to a variety of software applications. Currently, all the files of processed deer stones are archived at MCI under site-specific project numbers, and can be copied to a CD with a free viewer program for distribution.

Fig.18 3D visualization of the PLY file of an Avtiin deer stone

Fig.19 Avtiin deer stone as picture

7. Conclusion

Within a three-week period in July 2007, fifteen 3000-year-old deer stones, with dimensions from 0.5 meter to 3 meter high, were scanned with a robust Breuckmann tri*TOS* 3D scanner in Northern Mongolia at day and night.

The members of the expedition were especially impressed by the reliability of the system after an adventurous transport for more than 1200 miles over rough and smooth roads in all-terrain vehicles. With a laptop, electric power generator and a simple tripod, the system demonstrated its applicability for measurements in the field. Even variations in temperatures, between 32°C F at night and 122°C F in the day, did not influence the quality of 3D scans. Fine dust, blown by the wind through the Mongolian steppe, didn't affect the scanning.

By digitizing these significant monuments, which are not well recorded, and are at on-going risk of damage from environmental and human causes, the Deer Stone Project made a big contribution to permanently preserve many of deer stones.

The 3D data of the deer stones give the scientists the opportunity to study and document the engravings or small structures in the stones, and also compare stones of different locations.

The 3D acquisition of deer stones becomes more important because weather influences slowly disintegrate stones, and broken pieces disappear in the luggage of tourists.

In addition, the 3D data can be used to produce replicas of two deer stones for the Smithsonian National Zoological Park in Washington D.C..

8. Acknowledgement

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9. References

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