3-D Scanning in Truly Remote Areas

by Christiane Bathow and Mel Wachowiak

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 3-D scan data of stone monoliths from the Bronze Age. This expedition was characterized by traveling in Russian all-terrain vehicles for more than 1,200 miles across country and on dirt tracks, passing through rivers without bridges, changing weather conditions, extreme temperature differences each day, sandstorms and thunderstorms, being many miles from any modern civilization, and scanning under the stars.

INTRODUCTION

The American-Mongolian Deer Stone Project (DSP) is a research project of Mongolian archaeologists, the Smithsonian Institution (i.e., 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 performed 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 from the first to second millennium B.C.E. and earlier, using a 3-D scanning system. Beginning in 2006, a Breuckmann 3-D scanner was used. After that successful first trip in 2006, a Breuckmann system again played a key role for research in Mongolia in 2007. The 2007 on-site project group included Harriet F. Beaubien, Paula DePriest, Ph.D., William W. Fitzhugh, Ph.D., from Smithsonian Institution and his team, Mongolian archeologists, and Christiane Bathow from Breuckmann GmbH.

The 3-D imaging component is of particular importance, as it allows precise and high-resolution metrological information, describing the surface geometry of a 3-D 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.

INTRODUCING DEER STONES

Deer stones are Mongolian ancient megaliths between 0.5 meters and 4 meters in height, that are carved with symbols such as flying deer. In addition, 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, and their creators, are unknown. More than 550 deer stones have been identified in Mongolia's grassy steppe region. They occur singularly, in small groups, or they may be concentrated in larger groupings. Bronze Age nomads presumably erected deer stones approximately 3,000 years ago.

Figure 1. Avtiin deer stone

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

Figure 2. Khushuugiin Devseg deer stone

SCANNING SYSTEM AND EQUIPMENT

In 2007, a Breuckmann triTOS 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.

The triTOS consists of a sensor bar with a projector and a color camera (1,384 × 1,036 pixels) 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 a field of view (FOV) of 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 triTOS system is a topometric system that makes use of the principle of optical triangulation in combination with structured illumination. The 3-D 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 3-D 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.

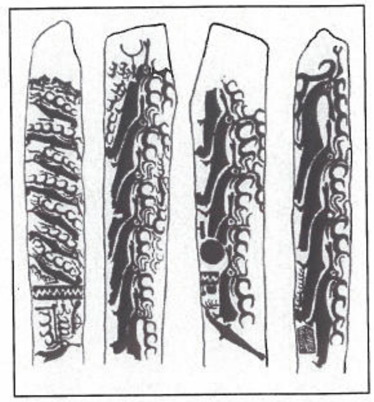

Figure 3. Drawing of Uskiin Uver deer stone

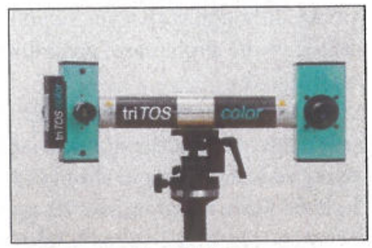

Figure 4. triTOS scanner

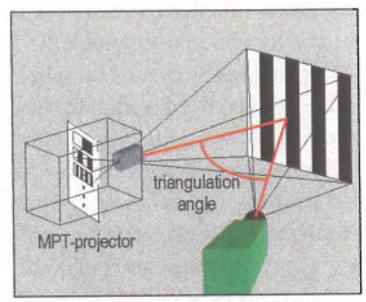

Figure 5. Mode of operation of atopometric sensor

TRAVELING THROUGH MONGOLIA

The scanning team, Harriet F. Beaubien and Christiane Bathow, arrived in Mongolia on June 5, 2007, meeting up with other members from the DSP team in Ulaanbaatar.

From Ulaanbaatar the entire team of about 20 people, including 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 the scanning equipment in the trunk of the van were given a good shake. Other highlights of the trip to the north included crossing torrential rivers on decayed timber bridges with more than one ton of weight in all-terrain vehicles and important equipment on board, driving through some rivers when no bridges were available, and getting stuck in the mud and having to push the car

Figure 6. Driving through the Mongolian steppe

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.

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 3-D 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, 3-D digitizing of the deer stones took place during the day or night.

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 triTOS sensor needed to be covered 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.

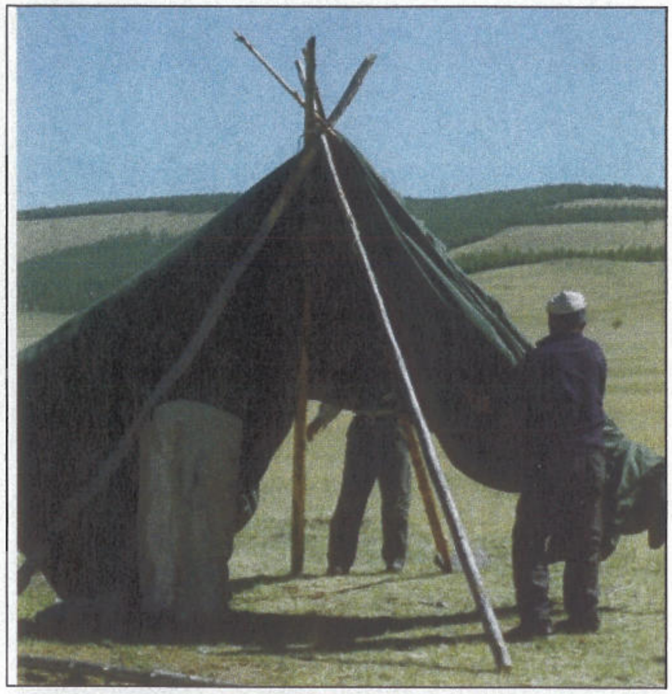

Figure 8. Avtiin deer stone with shelter setup for daytime scanning

Although 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 one half to two hours. After setting up and calibrating the system the scanning team was already sweating, and felt as if they were in a sauna.

In the northern Darkhad Valley beyond Tsagaanuur (which was very close to Siberia and the team's first destination for daytime scanning and archeological research), the weather changed 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 the generator outside the shelter got wet. Of course, when this happened the scanning team 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.

Figure 7. Pulling the van on the other side of the river

Figure 9. Daytime scanning in shelter

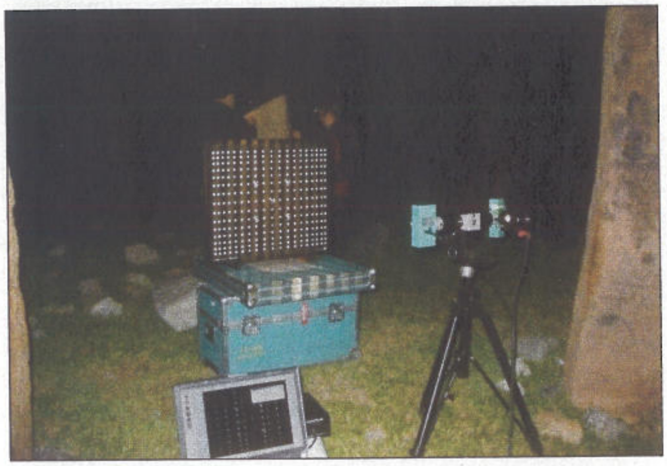

Figure 10. *System calibration (foreground) and cleaning monoliths (behind calibration plate) with bamboo skewers and toothbrushes to remove accretions*

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 the 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 the base camp at Khushuugiin Devseg and Khyadag, which was an easy one-hour drive by van. Furthermore, the stone monoliths of this region have a larger height than the stones that the scanning team digitalized in the far north. The nearly three-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.

Figure 11. *Khushuugiin Devseg deer stone being scanned at night*

Figure 12. *Covering a metal cage with canvas for daytime scanning in Hovsgol Museum*

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

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

Although 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 in particular, thick gloves.

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.

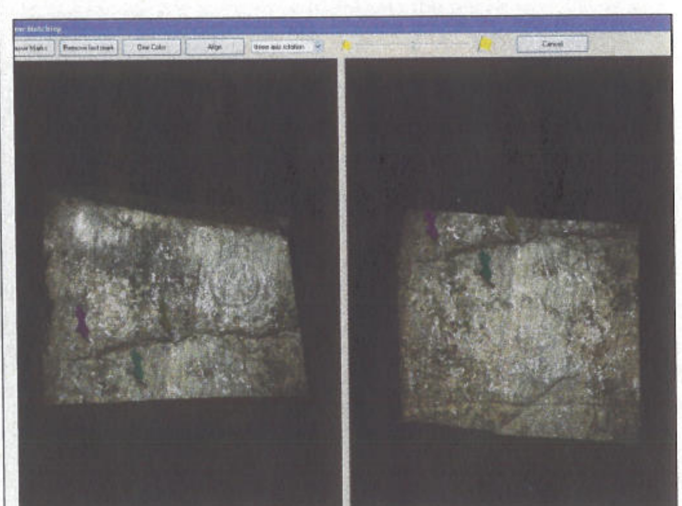

Figure 13. *Pairwise alignment of adjacent scans*

Figure 14. 3-D visualization of the PLY file of an Ushkiin Uver deer stone fragment

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 two-and-a-half 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.

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 after the expedition by Basiliki Vicky Karas, an objects conservator and 3-D scanning specialist, at the Smithsonian Museum Conservation Institute.

The following processing steps were carried out to convert the raw point clouds to 3-D visualization:

Figure 15. Ushkiin Uver deer stone fragment as picture

- Registration (alignment)
- Pairwise registration
- Global registration
- Point-cloud editing
- Merging
- Hole filling
- Visualizing

To create an 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 3-D 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.

Because the scanning system records the point cloud (XYZ) and color values (RGB) together, the color information is registered exactly with its corresponding 3-D 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.

Figure 16. 3-D visualization of the PLY file of an Avtiin deer stone

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.

The PLY format is designed to store 3-D 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 3-D 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 files, 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.

CONCLUSION

Within a three-week period in July 2007, 15 of these 3,000-year-old deer stones, with dimensions from 0.5 meters to 3 meters high, were scanned with a robust Breuckmann triTOS 3-D 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 1,200 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° F at night and 122° F in the day, did not influence the quality of 3-D scans. Neither did fine dust, blown by the wind through the Mongolian steppe.

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

The 3-D 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 3-D acquisition of deer stones becomes more important because weather is slowly disintegrating the stones, and broken pieces are disappearing in the luggage of tourists.

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

ACKNOWLEDGEMENT

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Figure 17. Avtiin deer stone as picture

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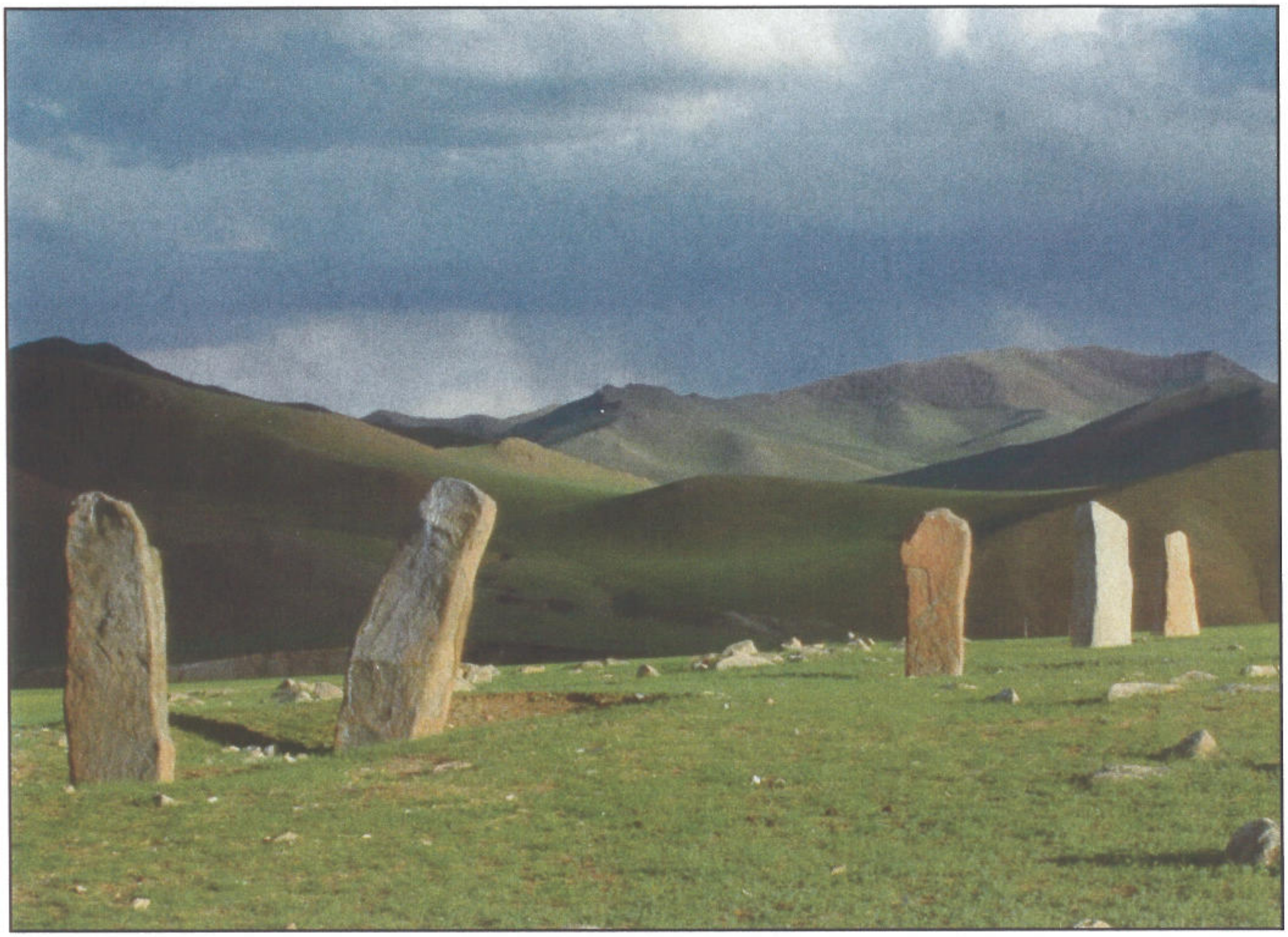

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