PHOTOGRAMMETRY: FROM FIELD RECORDING TO MUSEUM PRESENTATION (TIMIRYAZEVO BURIAL SITE, WESTERN SIBERIA)

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ABSTRACT

A 3D-recording project was introduced into practice in 2014 by Tomsk State University during investigation of Timiryazevo burial site (5th–10th centuries AD). During the excavation, three-dimensional models of the whole archaeological site were made at each stage, as well as individual records of all artifacts. 3D recording was conducted by SFM technology. The data obtained was used for research and in work on the exhibition project "Secrets of Timiryazevo Burial Site: The Circle of Life and Death in Siberian Shamanism". The exposition centers on unveiling the meaning of the rite of burying lookalike dolls of the deceased, which was practiced by many indigenous peoples of Siberia. The exposition is designed to enable the visitor to pass through the whole cycle of knowledge extraction together with archaeologists, the "detectives of the past": from a bunch of strange miniscule objects found in the sand to reconstruction of the whole sophisticated rite of the "ultimate funeral" including the burial of the deceased's lookalike doll. The tools used to develop the topic included a stereoscopic video created with Autodesk 3D Studio MAX 2014 and displayed in the exhibition. Stereoscopic videos displayed by specialized museum equipment create a total participation effect, enabling any visitor to watch excavations step by step, in all their detail and from all perspectives.

INTRODUCTION

Buried underground and "invisible" to the public at large, the archaeological sites of the Siberian taiga do not enjoy the visual appeal required to popularize science. Moreover, the archaeological sites in taiga have no stone monuments, meaning special conditions must be established in order to turn them into museums. Construction of open-air archaeological parks and development of educational tourism in deep Siberian taiga is practically impossible, as there is no necessary infrastructure or proper transport connections with the nearest localities.

The last decade has introduced methods of three-dimensional documentation and rendering of information uncovered by excavations, opening up entirely new opportunities in presenting scientific discoveries and bringing home their significance to the public. Now, photorealistic interactive 3D models make it possible for anyone to see archaeological sites. Stereoscopic videos displayed by specialized museum equipment create a total participation effect, enabling any visitor to watch excavations step by step, in all their detail and from all perspectives.

Unfortunately, however, laser scanning and close-range photogrammetry have not yet gained due currency in Siberian archaeology or anywhere else in Russia (Zaytseva, 2014). To date, there are only preliminary reports on using 3D scanning techniques in the field. There have been no publications about Russian projects using 3D recording consistently at all stages of excavation, except for the international project for 3D recording of archaeological sites in Altai Mountains dedicated primarily to rock art documentation and digital preservation (Plets et al., 2012a, Plets et al., 2012b).

In 2014, Tomsk State University investigated Timiryazevo burial site (5th–10th centuries AD) located in Western Siberia, in the lower reaches of the River Tom. This is the largest burial site of its time in Western Siberia, occupying an area of over 19 ha. The site has small burial mounds as well as underground tombs unpronounced in the contemporary relief. Investigations on the burial site were intended, in particular, to determine its boundaries more precisely. Geophysical studies identified several promising excavation areas on the peripheries of the burial site.

It was decided to record the whole excavation process using the Structure from Motion (SfM) technique, in addition to the traditional methods of field recording.

One of the excavation sites revealed not only graves but also some curious ritual artifacts representing isolated clusters of minuscule objects—miniatures of real ones, such as iron knives, adzes, buckles, arrows, jewelry, ceramic vessels and bronze masks. The discovered objects were interpreted as burials of the dead's lookalike dolls, typical of many Siberian peoples (Kulemzin, 2006, 86-87).

Bronze masks served as faces, while other parts of the dolls were made of organic materials that did not survive. Miniature objects buried together with bronze masks represent, in fact, funerary gifts for those dolls. Timiryazevo burial site reveals the most ancient and prominent records of this rite. When someone died, their soul would go into a small specifically designed doll. They would treat the doll as a living human being, feeding it, putting it into bed, and dressing it in special clothes—exact miniature copies of shirts and fur coats worn by living people. Some years would pass before the soul of the dead person would incarnate into a newborn of the same family. At this point the doll would be taken to the cemetery and buried with its "personal" possessions close to the grave of the real person.

3D recording using the SfM technique was performed at all excavation stages and for all the objects discovered, allowing for prompt and highly precise documentation of the surveys. The technique was also applied in the development of the exhibition project "Secrets of Timiryazevo Burial Site: The Circle of Life and Death in Siberian Shamanism". The exposition is designed to enable the visitor to pass through the whole cycle of knowledge extraction together with archaeologists, the "detectives of the past": from discovering a bunch of strange miniscule objects lying in the sand to reconstructing the whole sophisticated rite of the "ultimate funeral" including the burial of a dead person's lookalike doll.

1. METHODS

The excavation site where the ritual lookalike dolls were discovered had measured 8 x 14 m, with an area of 112 m^2 and a perimeter of 44 m. The excavation process was recorded using the SfM technique, allowing construction of 3D models from ordinary overlapping photos. The imaging process was executed by taking conventional photographs of the scene using uncalibrated cameras and lenses (Luhmann et al., 2011, 30-32).

There were two conventional types of recording used:

1. Recording of the whole excavated area prior to excavation and at different excavated levels
2. Detailed recording of each archaeological object discovered in the excavated area (burials, burials of lookalike dolls, funerary complexes, etc.)

1.1. Survey planning

To survey a large excavation, photographs of the surface are usually taken from an elevated direct-down position using special photo camera suspension systems (Miyatsuka, 1996; Mozas-Calvache et al., 2012). Mounting and using such equipment in an excavated area leads to a dramatic increase in the time of recording. Therefore, we decided to document the excavation from an ordinary monopod located 1.5 m above the site (*Figure 1*).

GSD Calculation

Ground sample distance (GSD) was calculated to determine the resolution that such a survey would provide (Leachtenauer and Driggers, 2003). The calculations were based on the assumption that one photo pixel would match up to one point in the final 3D model. The following formula was used:

$$GSD = \frac{l}{f}D \qquad (1)$$

- l is the length of 1 pixel on the camera sensor
- f is the focal length
- D is the distance from an object

We used the highest possible resolution provided by the photo camera used (Nikon D700 - 4256 x 2832) and the shortest possible lens focal length (Nikkor AF-S 24-70 F/2.8 G - 24 mm) in our calculations.

As long as recording was not performed perpendicularly to the surface, we calculated two GSD values, the lowest one for the area closest to the survey points and the highest one for the most remote area. *Figure 1* shows the overall schematic of recording used in calculations.
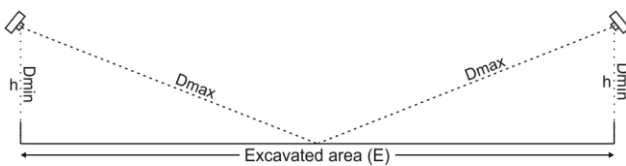

Figure 1. Survey plan (profile view)

$$D_{min} = h \qquad (2)$$

$$D_{max} = \sqrt{h^2\left(\frac{E}{2}\right)^2} \qquad (3)$$

- D_{min} is the minimum distance from an object
- h is the point of elevation
- D_{max} is the maximum distance from an object
- E is the width of the excavated area

The following parameters were used for calculations: h = 1.5 m—corresponds to the level of the camera supported by the monopod; E = 8 m—is the maximum width of the excavated area.

$$GSD_{min} = \frac{l}{f}D_{min} = (0.008458 / 24) \times 1.50 = 0.00053$$
$$m = 0.53 \text{ mm} \qquad (4)$$

$$GSD_{max} = \frac{l}{f}D_{max} = (0.008458 / 24) \times 4.27 = 0.00151$$
$$m = 1.51 \text{ mm.} \qquad (5)$$

The resulting GSD value conforms fully to the general survey resolution requirements.

GSD for individual objects discovered in the excavation site was calculated assuming a distance of 1 m from an object.

GSD = 0.008458/24x1.0 = 0.35 mm, which is also enough to provide the required survey resolution.

1.2. Data collection

The survey was performed from the border of the excavation area. The camera was hovering 1.5 m above the surface at an angle of 25°–30° to the horizon. Each photo effectively used the frame size: the excavated area took up the maximum zones on photos. The baseline was 0.2–0.3 m. Each recording took from 300 to 450 photos. Every scene was referenced by ground control points (GCP) located at the corners of the excavated area. GCPs were measured by total station Trimble M3 DR5. It took 10–15 minutes to document each excavated level.

Individual objects were surveyed in two stages. The first stage involved taking a 360 degree panoramic photo with 10°–15° between photos, each of them covering the whole scene including GCPs. The second stage involved taking photographs of the object from a direct-down position with 70–80% overlap. Every scene was referenced by 5 GCPs.

1.3. Data processing

A fairly broad choice of software is available today to build 3D models based on digital photogrammetry (Remondino et al., 2012; Koutsoudis et al., 2014). We selected Agisoft PhotoScan Professional software (Agisoft LLC, 2016a)

Data was processed using Intel Core i7-3960X 3.3GHz, 64GbRAM, nVidia Quadro 5000 2Gb, Microsoft Windows 8 64bit computer.

Construction of 3D models included five steps: estimating image quality (i); aligning photos (ii); building a dense cloud (iii); building mesh (iv); building texture (v).

At the first stage, image quality was estimated automatically. PhotoScan calculated quality parameters based on the level of sharpness of the most focused part of the picture (Agisoft LLC, 2016b, 12). Images with a quality value of less than 0.5 units were excluded from photogrammetric processing.

Photo alignment was performed using the parameters of accuracy (high) and pair preselection (gener-

ic). At this stage, the program calculated internal camera parameters and relative orientation of images. To process the alignment, Agisoft PhotoScan used the SfM approach (Ullman, 1979; Szeliski, 2011). The result was a sparse point cloud representing the geometry of the excavated area (Figure 2). The process of photo alignment took from 30 to 50 minutes.
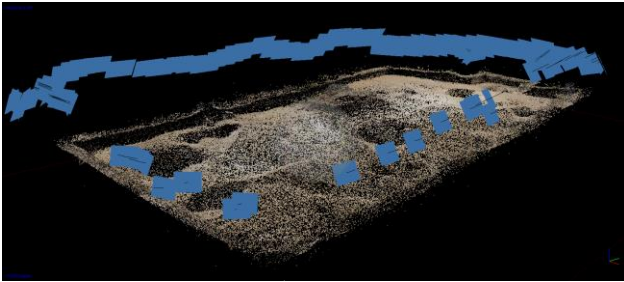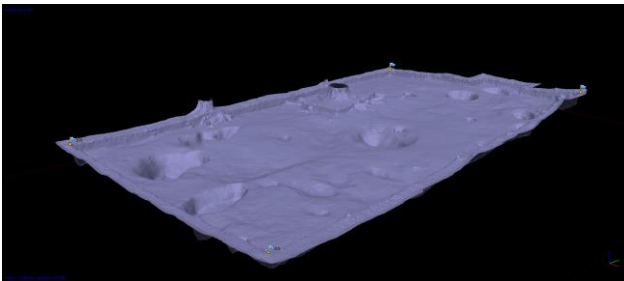

Figure 2. Excavated area. Sparse point cloud

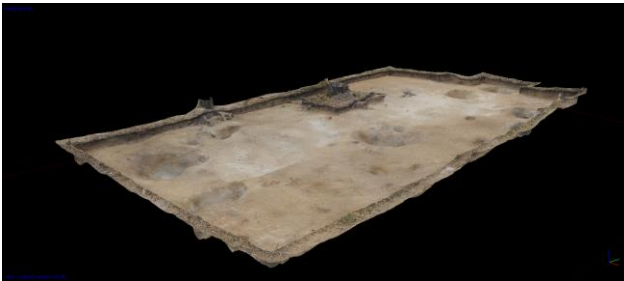
Figure 3. Excavated area. 3D model without texture

Figure 4. Excavated area. Textured 3D model

At the dense cloud building stage, the program calculated depth information for each photo to be combined into a single dense point cloud. At this stage Agisoft PhotoScan used dense, multi-view stereo-matching algorithms for processing (Scharstein and Szeliski, 2002; Seitz et al., 2006). The medium quality value was used to survey the whole excavation site, providing a model resolution of about 2 mm. Individual objects were surveyed with an ultra high quality value providing a resolution of up to 0.2 mm. Processing took from 1 to 3 hours at this stage, depending on the size and resolution of objects.

At the mesh building stage, the program connected points in the dense cloud to each other and formed the shape of a 3D model (*Figure 3*). Both types of recording used the "face count: high" parameter

to provide the maximum amount of detail in the model. The process of mesh building took about one hour.

At the texture building stage, the program calculated a texture atlas from the photos included in the project (*Figure 4*). 8000x8000 pixel resolution texture mapping took about 10 minutes.

As a 3D model was built, it had to be referenced to the corners of the excavation site (4 points). The average reference error calculated in Agisoft PhotoScan (Error (m) parameter in Reference Tab) was 5 mm for both types of surveying. The models were exported with a resolution of 2 mm and had about 7 million polygons each.

Over 9,500 photos were taken during the survey of this excavation site, which served as the basis for 70 models: 4 models of the excavation site at different levels, 5 models of lines and 61 models of objects at different stages of clearing.

Full-color 3D scanning of bronze masks and miniature tools discovered was also performed at a lab using an Artec Spider scanner with a final model resolution of 0.1 mm. The scanner has a field of view of 90 x 70 mm to 180 x 140 mm, depending on the distance from an object. Positioning is performed on the basis of geometry and color. This type of positioning imposes some restrictions, however. Scanning should be performed continuously in a single session, because once the position is lost, it is extremely hard to trace back to the previous one and resume scanning. An artifact should have well-defined geometry and texture. The object should have no flat, unvaried surfaces the area of which is greater than the area covered by the scanner.

Not only do size and color matter in scanning; the form of an object is also very important. In our case, most scanned artifacts represented flat-like objects, which complicated the scanning procedure. Let us consider the example of one of the bronze anthropomorphic masks discovered during excavation.

The mask had a size of 47 x 19 x 5 mm. The scanner coverage area was twice as large as the artifact, which also was flat-like and had a monotonous texture. In such a situation, there is a major risk of losing the scanner positioning during digitization. As a solution, the object is mounted on a special base, which should be multicolor, rich in contrast, opaque and full of various tiny elements with clear boundaries between them. Thus, the scanner can use not only the object itself but also the color of the area around it for positioning. In this case, the scanned artifact should remain fixed against the colorful base.

Flat-like objects present another digitizing issue. After bilateral scanning and removing of the base, the overlap region of two models will be extremely small, and the overall model can undergo great

width distortion during superpositioning. Another auxiliary model was constructed to solve this problem. The mask was scanned additionally in an erect position, and the resulting model identified precisely the mutual arrangement of the front and rear planes and the distance between them.

Next, the basic models were aligned with the auxiliary one. As soon as the basic models were properly aligned, the auxiliary model was deleted. The current model then was exported with a maximum resolution of 0.1 mm. The resulting model had a total of 474,850 polygons (*Figure 5*).
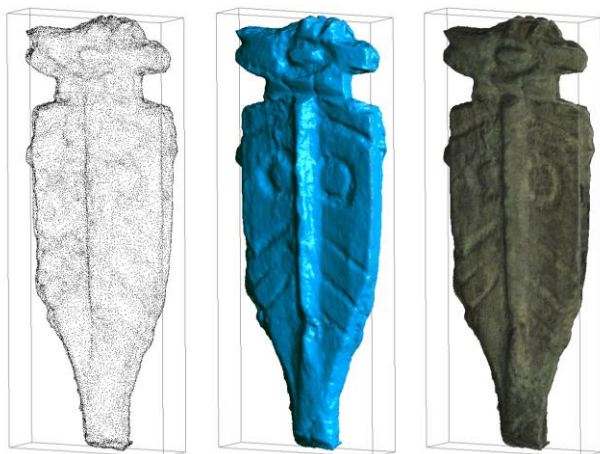

Figure 5. 3D model of the bronze mask

The Artec Spider scanner is able to capture textures in a rather high quality, but this object was too miniscule to build a quality texture. For this reason, we used photo textures. In our case, we were equipped with a Nikon D700 photo camera with a Sigma 105mm 1:2.8 DG MACRO HSM macro lens.

Geomagic Wrap (http://www.geomagic.com) software was used to reorient the model, position it correctly in the local coordinate system and apply textures. 3D models of miniature artifacts and bronze masks constructed using this method were later animated and used in creating the museum video.

2. USING 3D VISUALIZATION IN MUSEUM PRESENTATION

Tomsk Regional Museum of Local History launched the multimedia exhibition "Secrets of Timiryazevo Burial Site: The Circle of Life and Death in Siberian Shamanism" in April 2014. Documentation of the whole excavation process using the SfM technique enabled the inclusion of 3D rendering of surveyed archaeological objects in the exposition.

The tools used to develop the topic included the stereo video displayed in the exhibition (https://youtu.be/MBHM6GyA48Y). The first part demonstrates all the stages of the burial site excava-

tion: excavation of the cultural layer at different levels, discovery and survey of the burial and the nearby ritual object—the cluster of miniature tools and an anthropomorphic mask. The visitor can see everything that the surveyors could see during the excavation. The second part of the video shows the reconstruction of dead people's lookalike dolls.

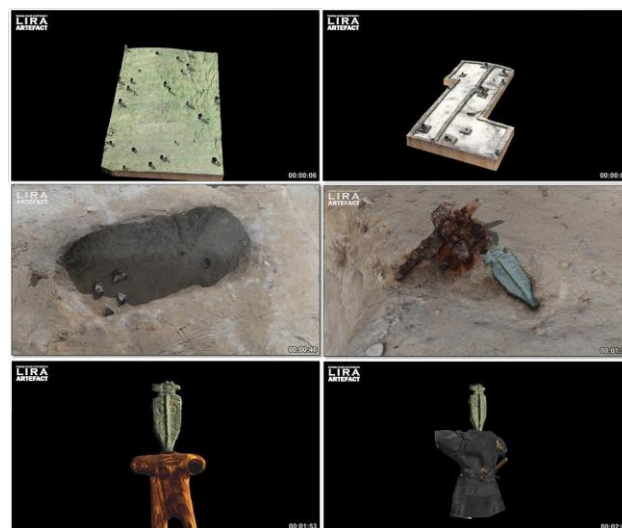*Figure 6. Demonstration of the stereo video in the exposition*

Figure 7. Thumbnails of the video

Before creating the animated scene, all the models were processed with Geomagic Wrap. We also attempted integrating models recorded at different scales: the model of the burial was integrated into that of the whole excavation site, the model of the local cluster of artifacts into that of the burial.

Autodesk 3D studio MAX 2014 (http://www.autodesk.com) software was used for rendering. We constructed a scene with seven models. Four of them were created using the SfM technique (the excavation site prior to excavation, two models showing the whole excavated site at different levels, the burial with the surrounding area, and an integrated model of the local cluster of artifacts). The other three were built by 3D scanning (a model of the bronze mask, a model of the doll's wooden

frame, a model of the reconstructed grave doll with its funerary gifts).

The scene used standard materials, lighting and cameras. No additional visual effects were applied. In order to create a stereoscopic image, the wall was rendered from two cameras using the directional method and a script to automatically calculate and modify the stereo base depending on the distance between the camera plane and zero parallax. In this case, we used a simplified formula of stereo base calculation:

$$B = 0.02L \qquad (6)$$

- B is the stereo base
- L is the distance from the camera plane to the zero parallax

The frames were rendered with a resolution of 1920 × 1080 pixels and saved as PNG images with an alpha channel activated. All in all, 6,000 frames were created (3,000 with each camera), which were used to make a video with the help of Adobe Premiere Pro CS6 (http://www.adobe.com). The frames were compressed twice in width and exposed side by side. The resulting video had a resolution of 1080p, a frame rate of 24 fps and duration of 2 minutes 5 seconds. The video was shown in the museum using a Benq W700+ projector and the NVIDIA 3D vision technology (*Figure 6*, *Figure 7*).

3.   CONCLUSION

The generation of 3D textured surface models using low-cost computer vision software and standard digital cameras provides opportunities for the extraction of 3D information from photographs and an accurate 3D registration of the archaeological heritage. In contrast with traditional photogrammetry or terrestrial laser scanning, it can be conducted by any archaeologist, even without a solid technical background in 3D technology (De Reu at al., 2013, 1117).

In addition to scientific value, a 3D model is more visible and perceptible for the general public. The implication is that the better the visual tool, the better the explanation and the comprehension of information (Hermon, 2008, 36).

The popularity of the exhibition Secrets of Timiryazevo Burial Site: The Circle of Life and Death in Siberian Shamanism currently on show in the Tomsk Regional Museum of Local History demonstrates the efficacy of using 3D tools for displaying archaeological heritage.

This clearly illustrates the importance and long-term benefits of using modern 3D recording techniques in field archaeology. However, Russian archaeologists are as yet mostly unaware of their availability, so they currently hardly ever use them.

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