УДК 004.032.2, 930.85

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3D SCANNING OF PETROGLYPHS – METHODOLOGY, TOOLS, RESULTS AND PROBLEMS

3D-сканирование петроглифов - методология, инструменты, результаты и проблемы

Петроглифтерди 3D-сканирлөө - методологиясы, куралдар, жыйынтыктар жана проблемалар

Annotation: *The article presents primary works related to the digitisation of rock drawings, or petroglyphs thich constitute the cultural heritage of Kyrgyzstan. The works were carried out in May 2019 in the "Petroglyphs of Cholpon-Ata" museum at Lake IssykKul. 3D scanning of 3-4 thousand-year-old petrogryphs in their natural environment was experimental in nature and was mainly aimed at verifying the adopted method and the equipment and software used, not an inventory of the entire area of their occurrence. The work was carried out as part of the 3rd Scientific Expedition of the Lublin University of Technology to Central Asia. The article confirms that the multi-stage method of preparation and planning of obtaining 3D data on petroglyphs, which were small-sized targets, with the help of a laser scanner intended for digitalisation of large architectural objects, turned out to be effective. The proper processing of the point clouds obtained from many scans allowed to build an accurate model of the artifact and its subsequent transformations into models that can be used in the Internet and in virtual reality systems. The paper shows that it is possible to minimise the time of digitisation, and thus the energy consumption, by limiting the angles of the scanning space and the number of scans performed, without detriment to the quality of the 3D petroglyph model obtained.*

Аннотация: *Представлены первичные работы, проведенные в мае 2019 года, связанные с оцифрованием наскальных рисунков – петроглифов, составляющих культурное наследие Кыргызстана, находящися в музее «Петроглифы Чолпон-Аты» на берегу озера Иссык-Куль. Работа направлена на проверку принятого метода, используемого оборудования и программного обеспечения, а не на инвентаризацию всего места нахождения.Работа проводилась в рамках 3-й научной экспедиции Люблинского технологического университета в Центральную Азию. Трехмерное сканирование 3-4 тысячалетних петроглифов в их естественном местонахождении носило экспериментальный характер. В статье подтверждается, что представленный многоступенчатый метод подготовления и планирования работ, получения трехмерных данных о петроглифах – объектах малого размера и их текстурах с помощью лазерного сканера, предназначенного для оцифрования крупных архитектурных объектов, оказался эффективным. Правильная обработка облаков точек, полученных в результате многих сканирований, позволила построить точную модель артефакта и его последующие преобразования в модели, которые можно использовать в Интернете и в системах виртуальной реальности. В статье показано, что можно минимизировать время оцифрования, ограничивая углы пространства сканирования и количество выполненных сканирований и, следовательно, потребление энергии, без ущерба для качества полученного трехмерного отображения петроглифа.*

Аннотация: *Кыргызстандын маданий мурастарынын бири - Ысык-Көлдүн жээгиндеги "Чолпон-Ата шаарынын таштагы жазуулар-петроглифтер" музейинде жайгашкан таштардагы сүрөттөрдү санариптештирүүгө байланыштуу 2019-жылдын май айында аткарылган алгачкы иштер баяндалды. Бул иштер экспонаттардын жайгашкан жерлерин тактоого багытталбастан, коюлган маселени чечүү ыкмасын текшерүү, керектүү аппараттык жана программалык жабдууларды изилдөөгө багытталган. Изилдөөлөр Люблин технологиялык университетинин Борбордук Азиядагы 3- илимий экспедициясынын алкагында жүргүзүлдү. 3-4 мин жылдар мурунку петроглифтерди алардын табигый жайгашкан абалында үч өлчөмдүү сканерлөө эксперименттик түрдө жүргүзүлдү. Макалада лазердик сканердин жардамы менен ири архитектуралык обьектерди үч өлчөмдүү сканерлөөгө тийиштүү колдонулган көп баскычтуу даярдоо жана пландоо ыкмалары кичине көлөмдөгү петроглифтерди сканерлөөгө да колдонуу эффективдүү экендигин тастыкталды. Көп этаптуу сканерлөө менен чекиттер булутун туура иштеп чыгуу артефактын так моделин түзүп жана аны андан ары Интернетте жана жасалма реалдуулук системаларында колдонууга мүмкүн болгон түргө өзгөртүү мүнкүнчүлүктөрүн түзөт. Макалада петроглифтерди үч өлчөмдүү чагылдыруу сапатын төмөндөтпөй, сканерлөө мейкиндигинин бурчтарын чектөө жана аткарылуучу сканерлөө санын, аны менен бирге сарпталуучу энергияны азайтууга жетишүү мүнкүндүгү белгиленди.*

Keywords: digitisation of cultural heritage; petroglyphs; 3D laser scanning methodology. ***Ключевые слова:*** *оцифровка культурного наследия; петроглифы; методология 3D лазерного сканирования.*

Урунттуу сөздөр: *маданий мурастарды санариптештирүү, петроглифтер, 3D лазердик сканирлөө методологиясы.*

1. Introduction

For three years now the Institute of Computer Science of the Lublin University of Technology has been organising scientific expeditions to Central Asia. The purpose of these trips is to obtain digital data on architectural monuments and museum artifacts in the countries along the Silk Road [1]. To this end we have used the latest information technology facilities, namely three-dimensional optical scanning of real objects. The process involves such modern devices as laser scanners with appropriate software (both builtin and external, used to process point clouds, surfaces of solids and their textures). The works are aimed at documenting the cultural heritage of Central Asian countries and its popularisation by using modern information technologies, namely the Internet, 3D imaging, virtual
reality (VR) or augmented
reality (AR) [2], [3].

During the 3rd Scientific Expedition of the Lublin University of Technology in Central Asia in May 2019 a possibility arose of digitising petroglyphs, whose fields are located in an easily accessible open-air museum "Petroglyphs of Cholpon-Ata" on the Issyk-Kul lake. Taking advantage of the opportunity, the team participating in the expedition decided to develop and test in practice an experimental method of 3D scanning of petroglyphs using a laser scanner. The method is a modification of one used to scan large architectural objects, carried out during the previous 2nd Scientific Expedition of the Lublin University of Technology to Central Asia [4].

Paper [5] considers the issue of the correctness of the adopted methodology to conduct research on the rock art of Central Asia. The author comes to the conclusion that a multidisciplinary approach and unified documentation can contribute to increasing knowledge and better protection of such sites. In this context, it seems that the use of modern computer technology of 3D graphics is absolutely necessary.

Works [6],[7] describe the use of 3D scanning for digital documentation of reliefs preserved in the form of estampages. For this pur pose, a stationary scanner for structural light was used, and the digitisation process was performed in a dedicated laboratory, and not in situ. In [8] a solution was presented that combines the digitisation of individual petroglyphs by a 3D scanner of up to 0.1 mm resolution and landscape data acquired by drone (unmanned micro-aerial vehicles). The whole was processed in Structure-from-Motion environment and tested in Valcamonica in northern Italy on an area of approximately 400 m2. The use of Structure-fromMotion technology to acquire 3D models of the famous deer stones located in Mongolia, and then converting them to the final drawing is described in [9].

The literature research shows that up to now no attempts have been made in Central Asia to acquire petroglyphs in situ in the form of point clouds using 3D scanners. The aim of the work is to develop a procedure for digitising 3D

2. Petroglyphs at the Issyk-Kul lake

Petroglyphs at the Issyk-Kul lake (Kyrgyzstan) were built in the period from the 2nd millennium BC until the 8th century AD [10]. Over 1,200 petroglyphs were inventoried on stones from 0.5x0.6 to 3x6 m in size, [11]. Many drawings are made in Saka-Scythian style and depict hunting scenes or map animals and people with primitive hunting tools (lasso, spear, bow, etc.), although there are more fanciful images [12].

Fig. 1. "Petroglyphs of Cholpon-Ata" museum towards the Kyrgyz Ala-Too range.

One of the most accessible is the open air museum "Petroglyphs of Cholpon-Ata", often called a stone garden, covering an area of about 42 hectares, being part of the Issuk-Kul Provincial State

Historical Cultural Museum-Reserve. So far documentation of the petroglyphs consisted in photographing them, sketching (copying) and marking the place of finding on the map of the area [13]. In the world, modern methods are increasingly used to document fields, such as GPS and GIS.

3. Methodology of 3D digitisation of petroglyphs using a laser scanner

3D scanning by means of a laser scanner consists in the automatic creation of a dense cloud of measuring points with simultaneous measurement (by digital photography) of the colour of each point. The laser scanner sweeps the space creating a sphere around itself and measures the distances to the points encountered by the laser beam on the surface of objects in this sphere. Only surface points to which the laser beam reaches directly are obtained, so it is necessary to perform multiple scans of the area while changing the position of the scanning device. The clouds of

points thus obtained in 3D space fragmentarily covering the scanned area are then properly processed using multiple algorithms (and programs) for 3D modelling and merged into one collective cloud containing all scannable surfaces of objects in a given area. On its basis, three-dimensional models of this area are built accordingly to the needs. Such models can be used for various measurements of objects (they contain high accuracy information about the geometry of the object) for documentation purposes or, after appropriate transformations, for the visualisation of objects in order to popularise knowledge about them.

The methodology of digitising petroglyphs using a laser scanner consists of the following stages:

I. **Planningwork**. Work in the field requires detailed planning of both a substantive character
(including getting to know the history of the petroglyphs, their dating, location, etc.) and its logistics (including how to get there, accommodation, obtaining appropriate permits and guardians, choosing the time of day and year, duration of work on the spot etc., including possibly access to the media.). Cooperation with researchers (among others) from a given country, city or museum is very helpful at this stage.

II. **Scanning**. It consists in the proper use of a laser scanner in order to minimise battery consumption, digitisation time and the number of partial scans performed (including determining the scanning area – defining the horizontal and vertical angles of the data collection area, defining the position of component scans, their resolution and other parameters of the process of obtaining a point cloud). During the scanning, large amounts of data are generated (for example, when scanning a 3D petroglyph, 600-800 MB of raw data are generated – about 150-200 MB for a single partial scan) which requires the use of secure carriers with a large capacity. It is also important to have spare batteries for the scanner, due to the frequent lack of access to permanent power sources in the field.

III. **Pre-processing of data**. Usually, 3-5 scans are made from various positions around a fairly simple artefact, such as a petroglyph. This is caused by the need to show all the surfaces of the object (in the case of petroglyphs – without the underside, for obvious reasons). As a result of many scans, further clouds of points are created, each in its coordinate system, determined by the location of the scanner. Pretreatment includes processes for cleaning scans from unnecessary elements, merging clouds into one, and converting all their coordinates to one system. At this stage, the elimination of duplicated points occurring on overlapping surfaces originating from different partial scans is also performed. These processes are carried out in manual-automatic mode with the help of specialised software.

IV. **Separation of the surface** – building a spatial model of the object. This process involves triangulation of the surface of selected objects, i.e. generating a large number of interrelated triangles located in three-dimensional space, creating an approximation of the surface of the real object, determined on the basis of the analysis of the distribution of points in the cloud. In the optimal case, a closed 3D solid is obtained that maps the shape of the object being scanned. Due to the large number of triangles in the model thus created, the automated procedure for reducing the number of triangles is often carried out at this stage.

V. **Texturing**. The finished model of the surface is overlaid with texture, i.e. colours, obtained as a result of processing photographs taken by the scanner during data acquisition.

VI. **Preparation of target models**. Depending on the expected result, 3D models (usually strongly simplified) are created using various programs, designed for different purposes (visualisation on the Internet, VR or AR). The size, and the subsequent accuracy of mapping the models and the formats of their recording depend in this case on the visualisation programs used and the requirements for the target models.

A Faro Focus X330 scanner using the infrared laser scanning method has been used during the implementation of 3D scanning of petroglyphs. Its parameters are given in Table 1. The programs listed in Table 2 were used to process data on particular stages.

Table 1. Parameters of the Faro Focus X330 scanner

No.	Parameter	Value
1	Scan range	0.6 m – 330m
2	Scan speed	up to 1 million points per second
3	Distance measurement error	+- 2mm
4	Measurement density (in points per square cm, at a distance from the scanner 0.6, 2, 10m)	11742, 1438, 42
5	Angular step of measurement	0.009 degrees

* Approximate measurement density calculated for a flat surface positioned perpendicular to the scanner.

Table 2. Programs used at particular stages of data processing

Stage	Name	Software used
I	Pre-processing of data.	Faro Scene
II	Fitting scans	Faro Scene
III	Generation of a common point cloud	Faro Scene
IV	Creation of the surface	MeshLab
V	Texturising	MeshLab
VI	Preparation of target models	Blender, MeshLab

4. Stages of an exeplary work

Detailed description of the procedure will be presented on the example of scanning of a petroglyph called "Hunting with tame snow leopards". This scan was carried out as an experiment to confirm the suitability of a stationary laser scanner to accomplish this task with sufficient accuracy. a)

b)

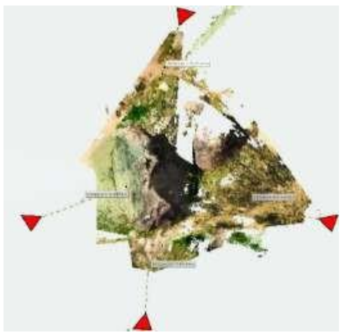


Fig. 2. Petroglyph scanning using the FARO Focus X330, a) general view, b) scanner positions.

The shape and location of the petroglyph caused that at the planning stage it was decided to implement 4 partial scans located around the petroglyph at a distance of 4-6.5 m, with the main scan positioned to cover the entire surface of the figures on the rock (Fig. 2b). At this distance, the average density of the distance measurements on the surface of the petroglyph made by the used scanner is approximately 1 mm. Due to the limited time it has been also decided to narrow individual scans to a circle segment covering the scanned stone.

a)  b) 

Fig. 3. Visualization of the object resultant point cloud (a), closed-up fragment (b).

Stage two – the scanning process proceeded without major disturbances. Individual scans were carried out within 12-15 minutes. Due to the small distance and narrow scanning area, it was possible to prevent tourists from entering the scanned area.The third stage was carried out after returning from the scan site. Individual scans were imported, processed and matched. A point cloud of approximately 20 million points was obtained (Fig. 3a). At this stage, it became apparent that the limitation of the scanning field (caused by time constraints) had a negative impact on the work of algorithms that adjusted partial scans. It caused the necessity of manual adjustment of scans.

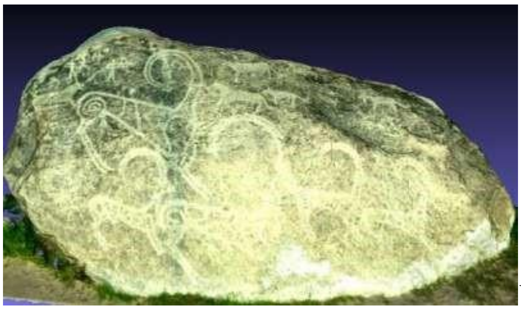
a)  b) 

Fig. 4. Visualization of the resultant triangle mesh of the object (a), closed-up fragment (b).

At step 4, it has been decided to generate the mesh model directly in a program for machining scans with the highest available precision. A model containing about 2 million triangles (Fig. 4) has been obtained. Due to the nature of the color measurement by the scanner, the model has color information stored directly in the vertices of the triangles that make it up (Fig. 3b). Limiting the number of triangles at this stage would result in a loss of detail in the image of the scanned petroglyph surface.

In the case of the discussed objectit has been decided to generate a version for presentation in the Internet at stages 5 and 6. The requirements were set to: a model no larger than 30MB plus a texture of maximum 8 MB in jpg format. The result was a *.obj* format suitable for internet presentation (Fig. 5). Free software such as Meshlab, Blender has been used at this stage.

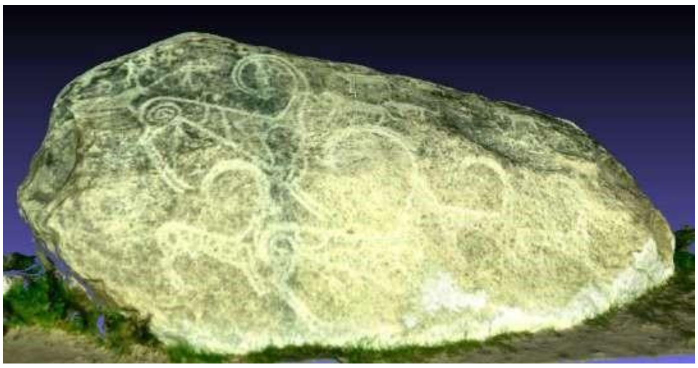


Fig. 5. An Internet ready version of the scanned object.

5. Problems arising in the course of work

In the logistics area, the biggest problems are:

- Access to objects. In addition to the few cases of publicly available facilities, the help of partners from universities, institutions and local museums is indispensable and invaluable here. This requires the development of appropriate relationships with partners and their commitment, and sometimes signing appropriate agreements that regulate and legitimise the activities.
- Air transport of equipment. Air transport imposes special conditions on the carriage of luggage. These are: a ban on the carriage of powered equipment and accumulators in checked-in luggage, weight limits and size of hand baggage, restrictions on the capacity of transported batteries, the need for obtaining special permits/licenses, customs clearance of high-value devices, etc.
- Access to the scanning location. Objects (including petroglyphs) often reside in inaccessible places in the mountains or in the desert, away from good roads, and may take many hours to reach, bearing in mind the time to return or find additional accommodation.
- Fatigue and discouragement of employees in the IT area who are not used to field work (e.g. in 32-degree heat or strong, cold wind blowing from the mountains).
- Necessity to work in a hurry conditioned by the desire to obtain as much data as possible at a given time, strongly limited finances, as well as, for example, museum opening hours and staff working hours, proper lighting of facilities, etc.

Practical problems mayappear at various stages and can be classified as follows:

- Incorrect planning of the scanner settings and scanning parameters, which may result in excessive time elapsed or a complex model.
- Disturbing environment. In this area, tourists are an important threat to the correctness of operation (objects are not closed during scanning); the weather and lack of adequate accessibility, due to irremovable fences, signs or even glass cases.
- High labour consumption (and demand for computing power) of data processing procedures that does not allow them to be implemented on site (due to time constraints or power outages).

6. Summary

The team's field work on 3D petroglyphs in the "Petroglyphs of Cholpon-Ata" museum on Lake IssykKul allows to draw the following conclusions:

- A Faro Fokus 330 laser scanner allows for effective digitisation of 3D petroglyphs – objects with dimensions not exceeding 2-3 m and quite shallow grooves of drawings with recesses below 2 mm.
- A compromise between the quality of the obtained data, the number of partial scans carried out of a single object (from 3 to 5), allowed for a significant minimisation of the scanning process time – up to about 50 minutes on one object without losing the quality of the digital 3D model.
- Application of the scanning space limit by defining the opening angle for the horizontal plane – values from 45o to 70o allow to shorten the scanning time about 3 times, but significantly complicates the submission of partial scans into one digital 3D model due to the difficulty of finding the right reference points in individual scans.
- Optimisation of the 3D scanning process of hard-to-reach objects (a long distance from the country of residence) is necessary due to the number of objects to be scanned and the willingness to collect as many practical experiences as possible for people involved in the protection of cultural heritage.

Acknowledgements

The authors – participants of the 3rd Scientific Expedition of the Lublin University of Technology to Central Asia – would like to thank prof. Nella Israilova from Kyrgyz State Technical University, Bishkek, Kyrgyzstan for her invaluable help in the implementation of the scanning in the Petroglyphs of Cholpon-Ata museum.

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