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ANALYSIS OF THREE-DIMENSIONAL SPATIAL STRUCTURES IN ARCHAEOASTRONOMY: 3D MODEL OF THE ROCK-CUT MONUMENT "BELINTASH", BULGARIA

Abstract: The report presents the visualization and analysis of three-dimensional spatial data taken with a drone photograph of the *rock-cut monument "Belintash", near the village of Mostovo, Asenovgrad Municipality, Bulgaria*. The same monument shows oriented structural details to certain positions of the Sun during its sunrise and culmination at the points of summer and winter solstice. The 3D model of the archaeoastronomical monument is a suitable example for each stage of image processing - obtaining the cloud of dots, as well as the subsequent orthomosaic and digital model of the relief of the monument. The analysis of spatial structures allows significantly more accessible and authentic extraction of archaeoastronomical data and their interpretation.

The created 3-dimensional model with high accuracy was used to build a *3D model of the rock-cut monument "Belintash"*. When loading the 3D model in specialized astronomical software Stelarium, a virtual astronomical observation can be performed from any place in space and during different time periods in the so-called "virtual walk in time". In this way we can see what astronomical events were observed by the ancient people of Belintash. *This technology is a unique tool for the needs of archaeoastronomy and the collection of authentic evidence to confirm archaeoastronomical hypotheses.*
Keywords: *3D models, unmanned flying vehicles, megalithic and rock-cut monuments, archaeoastronomical data and hypotheses*

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1. INTRODUCTION

Currently, unmanned flying vehicles (UFVs) are widely used around the world for terrain mapping, cadastral needs, monitoring of industrial facilities and construction, research, agriculture and more. The use of UFVs is increasingly replacing ground-based methods for data collection and analysis[1]. Existing image processing algorithms allow to automatically determine their spatial parameters and orientation. This process usually takes place in two stages: First, with the help of photographic image processing technologies, characteristic points are separated, which are used to calculate the spatial position and orientation of the images. After defining the image parameters, the main cloud of points is condensed. The density of the final cloud of points depends on the image quality, the degree of overlap

[1] REMONDINO 2011.

and the nature of the captured surface. The resulting cloud of points is used to build a surface model and subsequent orthorectification[2]. The last step is to create a mosaic of corrected images and the overall 3D model. GNSS (Global Navigation Satellite System) data from the flight controller can be used to determine the position of each image, which greatly simplifies the processing. For more precise work, additional control points are used, which allows to achieve accuracy comparable to that of geodetic measurements (1 - 2 mm in the horizontal direction and 1 - 2 mm in height).

Modern geographic information systems (3D GIS) have the ability to three-dimensionally represent a large amount of geographic spatial data, have the appropriate mobility, have a highly dynamic display and other features important for the support of 3D models. All this makes 3D modeling extremely important in the study of ancient archaeological objects as megaliths and rock-cut monuments[3].

In recent years, the use of unmanned flying vehicles (UFVs) as tools for remote mapping and documentation of rock-cut monuments has provided new and interesting opportunities. Aerodynamic improvements and access to accurate and miniature Global Positioning Systems (GPS) and inertial measurement units (IMU), as well as the availability of high-quality digital security cameras and other miniature sensors, have led to a qualitatively new approach to their use[4]. In this sense, Stöcker et alii[5] provide a detailed overview of the wide range of UFV remote sensing applications. In addition, a number of studies have successfully used unmanned flying vehicles for mapping and monitoring landscapes and detailed documentation of cultural and historical heritage sites[6].

2. ROCK - CUT MONUMENT "BELINTASH"

The rock-cut monuments on the territory of Bulgaria are located mainly in the Rhodope, Strandzha, Sakar and Stara Planina Mountains[7]. They show similarities with the rock sanctuaries in the ancient Anatolian cultures (Phrygian, Hittite, Urartian, Lycian), as well as with the Hellenic, Paleo-Balkan and Italic[8]. What is specific is that in the rock-cut monuments in Ancient Thrace there are all possible elements that are present singly or in combination in the above-mentioned other cultures - rock-cut rooms, stairs, sacrificial sites and sacrificial pits, altars, sacred caves, solar and stellar signs, votive niches, gutters for draining sacrificial fluids, etc. At the same time, the knowledge of rock cutting has been used very rationally in order to drain the rocky terrains and shape stone, wooden and adobe rooms. It is traditionally believed that the ancient Phrygians[9], who according to Herodotus moved from Thrace to Asia Minor and established their kingdom there, transferred their worship to the Mountain Great Mother

Fig. 1. Rock-cut structures in the "City of Midas", Republic of Turkey.

Fig. 2. Rock-cut site in the plateau of the "City of Midas", Republic of Turkey.

Goddess[10], famous in rock-cut sanctuaries[11], namely from the Thracian European southeast (the most famous rock-cut complex of the Phrygians is the "City of Midas")[12] (Fig. 1, Fig. 2). In the territory of Southeastern Europe and Asia Minor, the rock-cut holy places can be generally typologised as sanctuaries for confession of mass mysterious rites, for individual consecration rites, sanctuaries for doctrinal rites of closed societies, sanctuaries with necropolises, shrines for consecration rites through catabasis ("descent into the Underworld")[13] (Fig. 3, Fig. 4).

The rock sanctuary "Belintash" is located high in the Rhodope Mountains, above the villages of Mostovo, Topolovo and Dolnoslav, Asenovgrad municipality[14]. Its researchers consider it to be the second largest in Bulgaria rock-cut monument (after Perperikon), functionally connected with the Eneolithic temple complex near the village of Dolnoslav[15]. The last high mountain ridges of the Rhodopes separate it from the hilly part of the Thracian lowland. The sanctuary itself is located on a vast stone plateau with an area of about 5 acres, slightly sloping to the east, and on its highest part is

2 ARIAS *et alii* 2005.
3 BARNES/VOLKMANN 2015.
4 PEREZ/AGUERA/CARVAJAL 2013.
5 STOCKER *et alii* 2017.
6 REMONDINO 2011.
7 NAIDENOVA 1986.
8 RADUNCHEVA 2002.
9 MIDAS CITY.
10 ROLLER 1999.
11 BECKMAN 2007 .
12 MIDAS MONUMENT.
13 NEVE 1996; HATTUSA CITY.
14 HRISTOV 2009.
15 RADUNCHEVA 2002.

Fig. 3. Ritual pilgrimage to the great temple in Hattusa, Republic of Turkey.

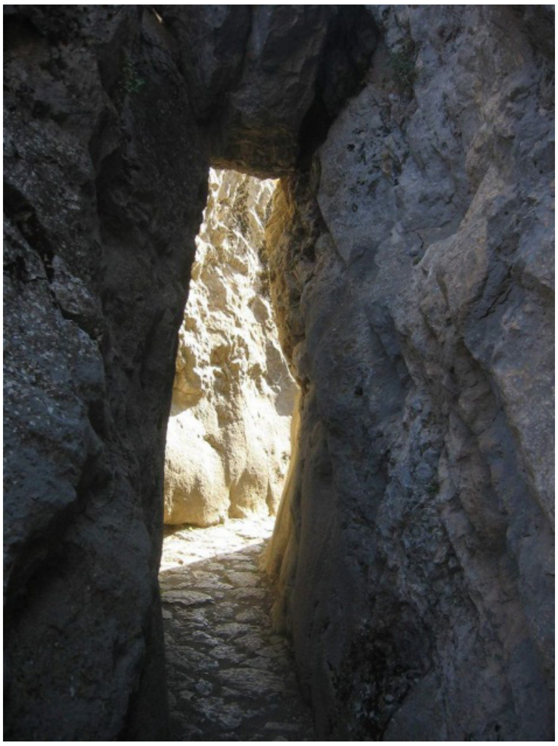

Fig. 4. Rock - cut corridors in the sacred territories of Hattusa, Republic of Turkey.

a rock platform-altar (Fig. 5, Fig. 6). It is about 300 m long and is very elongated in the north-south direction[16]. The rocks at its base, viewed from the North, in an appropriate position of the Sun, form a giant figure of a lying lion. This central part of the sanctuary is located in the middle of a wide circle of higher mountain massifs.

The platform - altar is well visible from each point of the outer circle of mountains and all the ceremonies performed on it could be observed. For an observer from the sanctuary these highest ridges of the outer circle form the line of the local horizon, where the daily sunrises of the Sun during its annual movement on the ecliptic occur. Probably, to this extremely unusual natural fact, which became a prerequisite for the choice of the place as a sanctuary, we

[16] BELINTASH.

Fig. 5. Rock - cut monument "Belintash" - view from the East.

Fig. 6. Rock - cut monument "Belintash" - view from the North.

must add the fact that the sanctuary is in the range of a very powerful magnetic anomaly. During excavations, a silver votive tablet with the image of the Thracian god Sabazios (Fig. 7, Fig. 8). , dated to VI - V century BC was found among the rocks at the foot of Belintash. It is stored in National Archaeologicl Institute with Museum of the Bulgarian Academy of Sciences[17].

Archaeological excavations in the second decade of the 20th century uncovered artifacts such as a silver cap from an unknown object, a bronze arrowhead, clay weights for looms and fishing nets, spindle vertebrae and part of an ancient metal melting vessel. The fragments of hearths-altars in which wine, milk and blood from sacrifices were poured certainly confirm the fact that the rock sanctuary dates back to the Eneolithic Age. The remains of an artificial wall have been discovered, probably separating the most sacred part of the sanctuary from the rest of the territory. The location of the front door in the wall supports this assumption. The open grooves for columns and traces left by its repeated opening testify to the fact that it was very massive[18].

[17] RADUNCHEVA 2003.
[18] BORISLAVOV/HRISTOV/HANDZHIYSKA-YANKULOVA 2014.

Fig. 7. Rock - cut monument "Belintash" - east wall and rock plateau (bird's eye view).

Fig. 8. Rock-cut well in the central part of the plateau.

Fig. 9. The upper part of the rock plateau, leveled for an observational ground with a rock-cut altar.

3. ARCHAEOASTRONOMICAL RESEARCH

The rock sanctuary "Belintash" consists of three connected parts - north, central and south. They were formed during the development of local tectonic processes, which created a system of oriented rock cracks in the monolithic rock block. The central part of the plateau has a slope of about 18° along the East-West axis. The rocks are rhyolites, with the characteristic geomorphological features of volcanic tuff. Two cylindrical pools with a diameter of 1.65 and 2.10 meters are cut in the main rock. Around them, a kind of stone seats (thrones) are formed also in the main rock. The pools are connected by a system of drainage channels and gutters designed to collect the precipitation waters. More than 260 round and elliptical holes have been found in the central part of the plateau. Geomorphological analysis shows that most of them are artificially cut in the rock.

The cult of the Sun played a significant role in the cults of prehistoric societies. The confession of the cult of the Sun requires not only specific religious and mythological notions, but also the presence of objective knowledge about its daily and annual movement on the celestial sphere. Archaeoastronomical research of the rock sanctuary "Belintash" showed that the line of the local horizon had a height in the range of 0 - 2° for an observer located on the central platform-altar (Fig. 9). The concentration of holes with an almost equal depth is in the East. Their maximal concentrations are located along the vectors of the summer solstice and the vernal equinox[19].

[19] STOEV *et alii* 1990.

In the course of the research, reference lines were sought for relief characteristics of the horizon line related to the distribution of the rock holes in the central part of the sanctuary. For the rigorous scientific research of this hypothesis, a geodetic survey of the rock plateau (relief and microrelief forms) was performed, as well as a study of the main lines of vision to near and far landmarks of the landscape, forming the visible horizon for the sanctuary observer[20].

The inclination of the ecliptic ε for the azimuths of the sighting lines to characteristic points of the visible horizon (formed by the vast circle of higher mountain massifs) is determined for an observer located on the platform-altar. Its average value is ε = 23.87 °, which gives grounds to support the thesis that in the period around 3000 BC the ancient skywatchers observed sunrises during the summer solstice and the spring and autumn equinoxes from the specially chosen observation ground dominating the altar plateau. Late Eneolithic cult pottery was discovered during research in the area of all these places in the surrounding mountains, selected as distant landmarks[21].

The position, structure and features of the rock sanctuary "Belintash" allow us to draw the following conclusion: The precisely leveled rock platform on two levels at the highest point of the monument serves to observe sunrises at astronomically significant points on the local horizon (solstice and equinox).

4. THREE-DIMENSIONAL MODELING OF THE BELINTASH ROCK CUT MONUMENT

Three-dimensional modeling (3D) is increasingly used in the study of sites on the list of archaeoastronomical monuments in Bulgaria and around the world[22]. The potential of three-dimensional visualization to provide a super-realistic concept of the studied archaeoastronomical object makes it possible to determine its relationship with

[20] STOEV/MAGLOVA/STOEVA 2000.
[21] STOEV *et alii* 1990.
[22] REMONDINO 2011.

Fig. 10. Three-dimensional model of 3D textured surface (Textured Mesh) of the rock-cut monument "Belintash".

Fig. 11. 3D model of the rock-cut monument "Belintash" together with its adjacent landscape.

important landmarks from the environment and objects from the celestial sphere. This serves the needs of a wide range of researchers of archaeoastronomical sites, such as astronomers, archaeologists, culturologists and others. Remote data collection methods (such as photogrammetry or laser scanning) allow the creation of detailed three - dimensional models of archaeoastronomical monuments and their associated area (Fig. 10, Fig. 11). This allows not only to register each stage of their geodetic, astronomical, archaeological etc. research, but also to analyze changes in them over time. Three-dimensional modeling related to data storage, precise documentation and attractive visualization of archaeoastronomical monuments is carried out through the so-called CAD modeling methods in order to obtain their correct geometric models. The development of three-dimensional models of archeoastronomical objects is successfully used for the preparation of information and presentation materials, as well as representative films, videos, virtual exhibitions and exhibitions in 3D format, interactive applications and more.

Three-dimensional modeling of archaeoastronomical objects allows to recreate the environment and landscape through perspective images, using a wide range of geospatial data: geographical, geological, architectural, geodetic, astronomical, etc., which are available or can be obtained through direct or remote measurements[23]. The main methods for collecting digital data in this case are three: remote, geodetic and cartographic.

a) Remote methods

The use of different sensors provides capabilities of collecting data that can be systematized and analyzed to obtain information about the studied archaeoastronomical sites. The format of the data collected may be different. This allows the processing of large data sets, directly obtaining three-dimensional information about the investigated surface of the area of the objects. Photogrammetric methods as the main part of remote sensing methods are: analog, analytical, digital, combined. Terrestrial photogrammetry is widely used in documenting, mapping and making three-dimensional models of archaeoastronomical monuments, regardless of their location on the territory. This method requires specialized and expensive equipment (photogrammetric cameras, stereo processing equipment, and software). Remote methods include LIDAR (Light Detection and Ranging) laser scanning systems.

b) Geodetic methods

As a result of direct geodetic measurements, vector data are obtained

for the terrain surface or individual elements of the archeoastronomical monument. It is possible to measure both the immediate quantitative values of the discrete elements (coordinates of points and lines) and other quantitative values (distances, directions, angles, etc.). These methods include different types of geodetic images: orthogonal, polar, etc.[24].

c) Cartographic method

By applying the cartographic method is achieved digitalization of the selected elements of the terrain surface of the archeoastronomical monument. Quantitative data (coordinates X, Y, Z) for the specific object are obtained. Digitization is performed on basic material (maps and plans), which has already been obtained by the other two methods, and in addition a certain generalization of data has been performed. Therefore, large-scale cartographic materials must be available for this purpose[25].

In the case of the 3D modeling of the Belintash rock-cut monument, the SfM (Structure of Motion) image processing method was used, which is based on matching characteristics (or dots) in multiple overlapping images. This automatically defines both the three-dimensional position of the camera and the geometry of the image[26]. The SfM method is based on the principles of photogrammetry, in which a significant number of photographs taken from different overlapping points of view are combined to recreate the object. This results in a 3D structure of the monument from the processing of a series of overlapping images.

However, the SfM method differs significantly from traditional photogrammetry. While classical photogrammetry relies on strips of overlapping images

[23] STOCKER 2017.
[24] PEREZ/AGUERA/CARVAJAL 2013.
[25] FONSAD *et alii* 2013.
[26] FONSAD *et alii* 2013.

obtained from parallel flight lines, in SfM the three-dimensional geometry of objects is recovered from random (disordered) images. However, an extremely important condition is that one physical point of the studied object is present in multiple images. The ease of use of the SfM method, the accessibility and the automated algorithm it provides, make it possible to use it when studying rock-cut monuments.

Several photogrammetric programs using the SfM method are in use. The most popular commercial solutions include Agisoft PhotoScan and Pix4Dmapper, which have become popular thanks to their user-friendly interface and support. There are also open source SfM solutions that include VisualSfM, OSM-Bundler, Photosynth Toolkit, OpenDroneMap and more. While SfM programs differ from each other, they all follow a common workflow, which, as well as the essence of the method, are discussed in detail by Dinkov[27]. Open source products also vary depending on the program. Some allow several steps to be performed, while others have only one step and must be combined with additional modules and software products.

Fig. 12. Observational ground at the top of the rock plateau with an artificial marker on the rock altar.

5. 3D SHOOTING AND THREE-DIMENSIONAL MODELING OF THE BELINTASH ROCK-CUT MONUMENT

The choice of the Belintash Rock Cut Monument is related to the registration of spatial data for three-dimensional modeling of a site that combines a unique natural landscape and cultural and historical value. The applicability of the data obtained from remote measurements is tested for development of a detailed and at the same time light (in terms of number of surfaces and nodes) three-dimensional model of the Belintash rock-cut monument and the possibility of integrating it into the overall 3D model of the rock sanctuary as an ancient observatory.

The performed activities for 3D imaging of the Belintash monument include the following steps in the work process for three-dimensional modeling:

• Preliminary preparation:

- Location of the test area,

- Selection, stabilization and measurement of ground control points (GCP).

• Photogrammetric shooting:

- Choice of unmanned flying vehicles (UFVs);

- Preparation of a UFV flight plan;

- Flying and filming.

• Data processing;

• Generation of digital products from the processed data;

• Creation of vector metric data for the object;

• Three-dimensional modeling and visualization;

• Development of a simplified three-dimensional model of the Belintash rock-cut monument;

• Integration of the three-dimensional model into a complex three-dimensional model of the Belintash rock-cut monument as an ancient astronomical observatory together with the adjacent landscape forming the horizon line.

Preliminary preparation:

a) Locating the test area for investigation, selecting, stabilizing and measuring ground control points;

The selected test area includes the rock plateau of the Belintash rock-cut monument (gutters, hollows, wells, foundations of buildings, other rock carvings), the approach to it in its vertical parts (stairs, platforms, sockets for railings) and the surrounding terrain (characteristic bearing peaks that form the horizon line and the main macro-relief landmarks). The first activity was to select appropriate locations to ensure visibility of the ground control points during the aerial surveying. After choosing the location for the control points, four control points were stabilized with temporary signs marked with signal spray - 1, 2, 3 and 4. The next stage of the field work was to measure their coordinates (Fig. 12).

b) Precise coordination of the ground control points (GCP);

In order to achieve centimeter accuracy in the georeferencing of digital products as a result of photogrammetric surveying, ground control points within the scope of the Belintash rock-cut monument were marked and coordinated. Ground checkpoints were signaled with appropriate cross-marks, which could be recognized in

[27] DINKOV 2018.

the images obtained after the execution of the flight plan. The coordinates of the used control points were obtained using a GNSS (Global Navigation Satellite Systems) receiver before and after the completion of the flight plan. This was done by real-time measurements with a geodetic dual-frequency GNSS RTK receiver (Trimble L1 GPS Reciver). The coordinates were measured in the WGS84 coordinate system and saved in a text file for further processing.

c) Preparation of a UFV (unmanned flying vehicle) flight plan;

In order to obtain high-precision results, a large overlap between the images was required. Therefore, the plan for flying and registering the images was designed so that the photos have sufficient overlap. The flight plan was also in line with the requirements for a resolution corresponding to the minimum size of the terrain element - GSD (Ground Sampling Distance). The resolution was determined according to the requirements of the study and the type of specific rock surface that had to be reconstructed. The required resolution - GSD according to the specifications of the final orthophoto mosaic determined the altitude at which the photos had to be taken.

d) Flight planning, implementation and control;

Freely available mobile software applications (in the Android Market) - Pix4DCapture, DJI GO, DroneDeploy - were used for flight planning, implementation and control. In view of the characteristics of the rocky terrain and the objects to be photographed (horizontal rock relief in combination with the surrounding vertical walls) it was necessary to conduct two different types of surveying flights. The first flight is a type of „double photogrammetric network" to cover and model the entire territory of the rock-cut monument. In the presence of vertical and hidden surfaces (such as the walls of the rock plateau) it was necessary to take additional pictures of the so-called „facade" elements. For this purpose, an additional free flight was planned and carried out around the Belintash rock-cut monument, as well as the survey of the three rock staircases leading to the rock plateau. The preparation, introduction of the basic parameters for flight performance and image recording was excuted in the medium of the Pix4DCapture mobile application.

e) Flight and filming of the Belintash rock-cut monument;

The flights were performed with the unmanned flying vehicle DJI Inspire-1. In terms of stabilization, stand and camera, DJI UAVs offer a stand-and-camera system that delivers high-quality, vibration-free UHD 4K. Image size - 12 Megapixels, Lens - 9 elements in 9 groups, including aspherical, Sensor - 1 / 2.3-inch CMOS sensor, 94-degree wide-angle FOV (Field Of View). The camera path is suspended on a 3-axis, fast-rotating 360-degree stand.

The first flight took place at an altitude of 100 m above the take-off point in the area of the rock monument, where a little over 4000 photos were taken. For the photos, a longitudinal overlap of 80%, a transverse overlap of 70% and an angle of the optical axis of the camera of 90 ° in relation to the direction of flying (ie normal to the ground surface) were set. The second flight was freely piloted and was performed through the DJI GO mobile device for real-time control and monitoring of the UFV's position and camera images. About 1200 additional photos of the rock-cut monument were taken during the free flight.

f) Digital flight data processing.

The software package Pix4Dmapper (https://pix4d.com/) was used for the processing of the photos obtained from the UFV flights of Belintash rock-cut monument. This software has been developed specifically for processing information from UFVs and the result is a variety of digital end products: orthophoto mosaic (orthophoto map), digital surface model (DSM) and digital terrain model (DTM) (after removing the influence of vegetation). The photos from both fields were reviewed and combined into a digital array for further processing. The total number of captured images was 5200. The photos from the camera and the data from the navigation system of the UFV are processed automatically in three main steps:

First step - initial processing

During the initial data processing, the key points calculated in overlapping images were identified, using an algorithm for recognizing terrain characteristics. Free flight images were subjected to additional masking to avoid unwanted detections during subsequent photogrammetric processing using the SfM method. These are areas on the horizon, in the sky and far from the scope of the rock object. Thus, the masked areas did not participate in the software processing, which saves computing resources and unwanted points in the 3D cloud. After performing batch alignment, the internal and external elements of the camera orientation are calculated, a dilute cloud of three-dimensional points is obtained, which can be visualized in RayCloud mode.

To achieve precise georeferencing of the object, the measured coordinates of the ground reference points have been added to the Pix4Dmapper register. After the introduction and marking of the ground control points, the initial processing was re-optimized. It includes optimization of the camera parameters and calculation of rotational and translational matrices, as well as a scale factor for the accurate georeferencing of the point cloud based on control points (Fig. 13, Fig. 14).

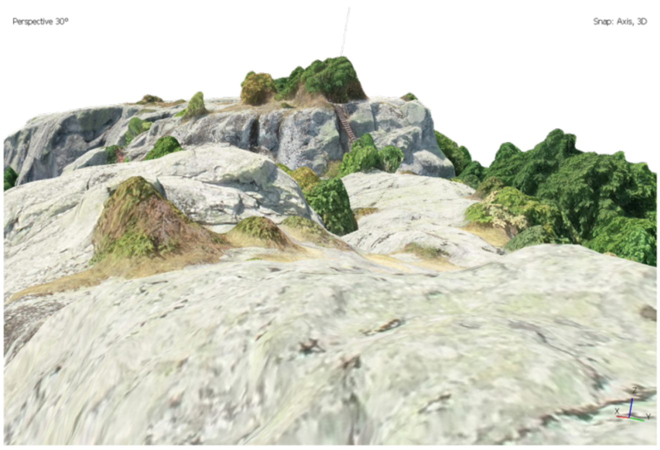

Fig. 13. 3D model of the rock plateau of the rock-cut monument "Belintash".

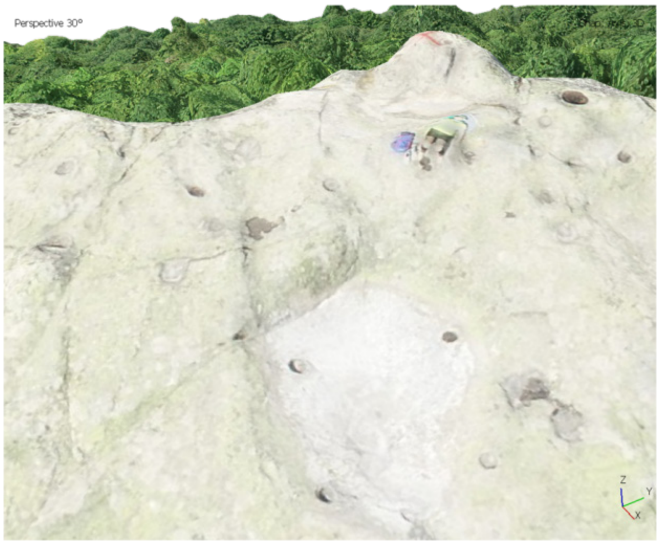

Fig. 14. 3D model of the observational ground and the rock altar of the rock-cut monument "Belintash".

Fig. 15. 3D model of the rock-cut monument "Belintash" with a view from the East.

Accuracy assessment - one of the most important indicators are the ground sample distance (GSD) values, where GSD is 2cm / pixel and the generalized mean square error in georeferencing the overall model, which for this study is 0.05 m (mean RMS error) using 6 reference points.

Second step - generate dense 3D cloud dots

In the second stage of the photogrammetric processing a dense 3D cloud of points is formed, which is calculated by the position of the camera and the elements of the external orientation determined in the first stage (Fig. 15, Fig. 16). It is this dense point cloud that is the basis for obtaining all digital products from automatic data processing.

Fig. 16. 3D model of the rock-cut steps leading to the central part of the Belintash rock-cut monument.

Fig. 17. Rock-cut monument "Belintash" - panoramic photo of the local horizon to the East.

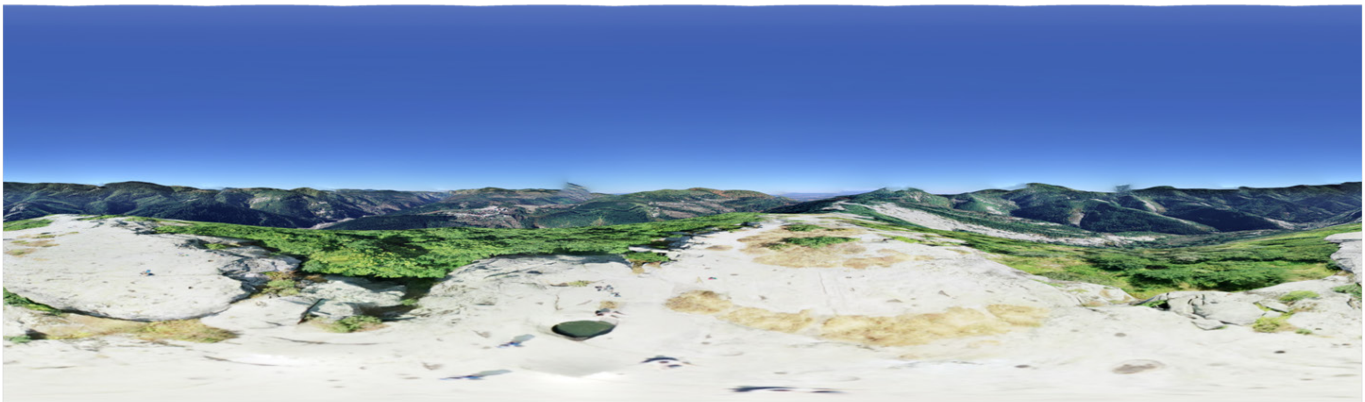

Fig. 18. 3D synthesized panorama of the eastern horizon of the rock-cut monument "Belintash".

Third step - generating digital 3D products

In the third stage of the processing of spatial information in Pix4Dmapper environment, various digital products were obtained from the calculated model of the actual object: orthophotoplan, digital surface model (DSM), digital terrain model (DTM), three-dimensional model of 3D Textured Mesh.

Due to the central perspective of the main amount of photos, in a relatively large part outside their central area the images are not orthogonal, but inclined. This makes it possible to see and decipher directly in many photos parts of the vertical and intermediate parts of the rock-cut monument. This made it possible to map linear elements and surfaces of the Belintash RCM with high accuracy. In the three-dimensional point cloud, distances between 3D points were found to find the height and length of the various elements of the monument. In a similar way, in the RayCloud editor it became possible to vectorize lines on surfaces, as all captured rock elements of the object, which can be displayed and used in various CAD and GIS software products. Visualizing a selected point in the spatial cloud and recognizing it on individual photos in RayCloud mode allows you to combine the cloud of 3D points and their 2D images recognized in individual photos. It is useful and important that this method of work gives good control over the calculated accuracy and the ability to check for the recognition of cloud points and their connection with the real elements and surfaces of the monument.

6. RESULTS

As a result of the field research, a sufficiently detailed and reliable three-dimensional model of the Belintash Rock-Cut Monument, the terrain around it and the landscape forming the horizon line for an observer standing on the monument was obtained (Fig. 17, Fig. 18). A careful view of the central part of the plateau shows that at its highest point there is a precisely leveled terrain on two levels. At the same time, this model had to meet the condition that it could be integrated into other 3D visualization applications, including those with pure astronomical content (Stellarium, C2A (Computer Aided Astronomy), KStars, Starry Night). The prepared virtual panorama of the line of the local horizon, visible from the higher level for the ancient observer, was placed in the astronomical software "Stellarium". "Stellarium" turned out to be the best choice for 3D simulation of the obtained 3D model of the rock sanctuary.

In this regard, the 3D Textured Mesh for the Belintash RCM and the vectorized lines and surfaces of the monument are digitally displayed (.obj, ESRI shape and AutoCAD DXF - formats) and used to build a three-dimensional model of the site. in CAD software. The comparison between synthesized images from Stellarium and a virtual surface in the 3D model of the Belintash RCM shows the connection of observational

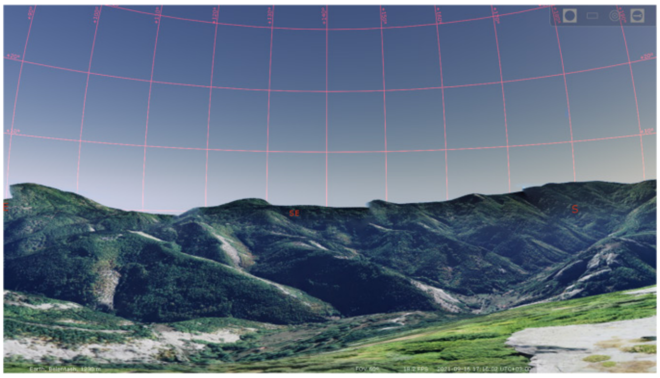

Fig. 19. 3D synthesized panorama of the eastern horizon combined with the coordinate network of the celestial sphere in the astronomical program "Stelarium".

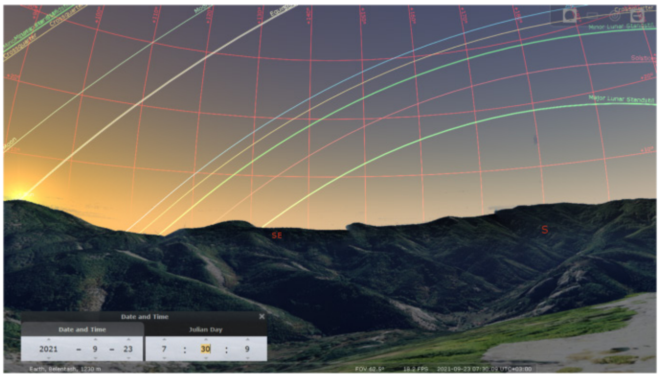

Fig. 20. 3D panorama of the eastern horizon with sunrise during the autumn equinox over the Sini Vrah peak (September 23, 2021).

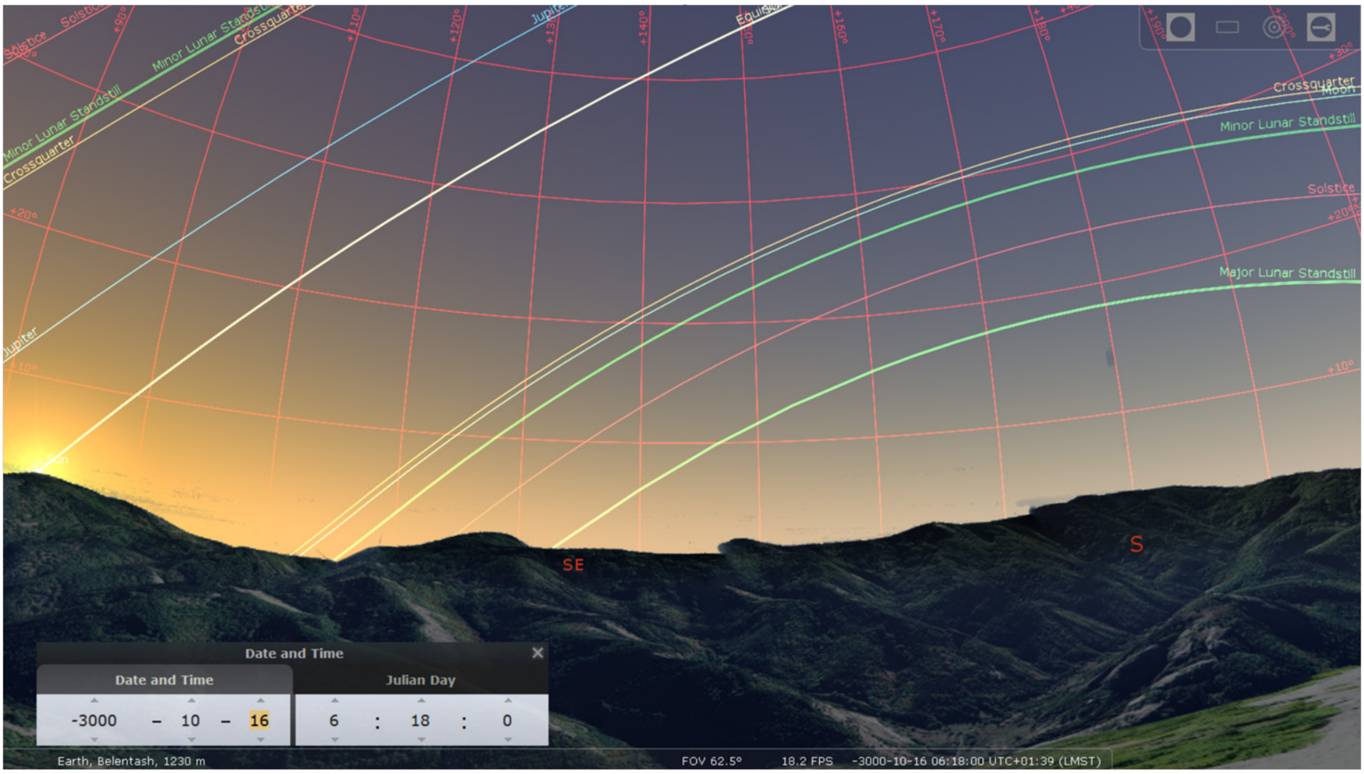

Fig. 21. 3D panorama of the eastern horizon with sunrise during the autumn equinox over the Sini Vrah peak (3rd millennium BC).

vectors from the peak site with characteristic relief features of the horizon (peaks, depressions, flat places) and sunrises during the summer solstice and both equinoxes (Fig. 19, Fig. 20). The simulation of virtual reality also showed the sunrises observed by ancient astronomers at a specific time, which makes the determination of the chronological boundaries of the existence of the Belintash RCM reliable (Fig. 21).

Preparation of the generated 3D digital data for three-dimensional modeling

The open source software MeshLAB was used to reduce the boundaries, the number of polygons and nodes in the three-dimensional surface (3D Textured Mesh). A simple and optimized model of the Belintash RCM was obtained through the provided set of tools for editing, cleaning, correcting, checking and converting such three-dimensional data.

Three-dimensional modeling of the Belintash rock-cut monument

In order to achieve an accurate geometric model with a minimum number of polygons, a new 3D model of the Belintash RCM monument was built. The modeling was done using the SketchUP 3D geometry creation software.

SketchUP solves standard geometry creation tasks in less time than traditional CAD software products. Its rich possibilities for import and export in various formats and the few but quite functional tools contribute to the choice of SketchUP for three-dimensional modeling of this type of rock-cut objects. An accurate geodetic plan is also available for the Belintash RCM, which improves some of the iterative procedures. For the exact scale and content of the 3D model, the textured surface prepared in MeshLAB and the vectorized lines and surfaces in the middle of Pix4D were used as input data. The following modeling steps are applied:

- Import the three-dimensional surface into SketchUP;
- Importing vector objects into SketchUP;
- Construction of the three-dimensional rock-cut site;
- Independent rendering of the rock-cut site;
- Export of the three-dimensional model, combination with a complex 3D model of the adjacent territory of the monument and three-dimensional visualization.

The final results obtained for the Belintash RCM region include the generation of the following digital products:

-Orthophoto mosaic for the area with a spatial resolution of 2.0cm / pixel;

-Digital surface model (DSM);

-Digital model of the adjacent terrain (DTM);

-Creation of vector data for surfaces, linear and circular rock-cut objects located on the surface of the monument;

- Three-dimensional model of the Belintash RCM with geolocation and optimized structure for visualization and embedding in the 3D model generated by the astronomical software “Stellarium” within the relevant chronological boundaries of the prehistoric observatory.

7. CONCLUSION

Remote sensing research with unmanned flying vehicles (UFVs) in the field experiments on the territory of the Belintash Archaeological Monument demonstrates the application of an innovative approach by using new tools and instruments for photogrammetric measurements to obtain spatial data for three-dimensional modeling of prehistoric rock monuments. This approach reveals an undeniably good and suitable alternative to expensive professional systems for terrestrial photogrammetry and laser scanning of archaeoastronomic objects.

Among the main advantages of UFVs for the acquisition of spatial information is the high efficiency of the invested financial resources, time and human resources. An important advantage is the high accuracy of the received data and the ability to obtain digital data in real time.

Another important advantage is the achieved high spatial resolution (2.0 cm / pixel for the Belintash rock-cur monument). In the development of the digital 3D model in the present study, available technologies and methods were used to achieve realistic, accurate and complete modeling and reproduction of the studied object and its relationship with sunrises during the solstice and equinoxes. The obtained results and the gained practical experience are based on the application of leading practices and tendencies in the modern geographical information systems (GIS), the three-dimensional modeling and visualization.

The rock-cut monument „Belintash" is a unique object for astronomical observations in the prehistoric era. The rock-cut observational ground at its top allows observations of sunrises in certain ecliptic positions of the Sun. Due to the significant horizontal parallax of the end points of the sanctuary, there is no other rock carving with the described characteristics and the existing landscape and artificial landmarks along the horizon. Also, the accuracy of the observations was probably improved by a developed system of close benchmarks, in the form of vertical wooden pillars standing in the holes cut into the main rock. The large number of such footholds can be explained by the long-term use of this observational device, which has necessitated the correction of nearby markers because of the movement of the sunrise point on the horizon due to the influence of precessionary movement of the earth's axis.

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