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НАУЧНАЯ СТАТЬЯ
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STUDY OF ADJACENT ROCK MASS CONDITION USING AERIAL PHOTOGRAPHY AT EKOLOG OPEN-PIT MINE

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Abstract: The article is dedicated to the use of air photography for adjacent rock mass monitoring with DJI Mavic 2 Pro drone at Ekolog Open-pit Mine. The survey objective is to create high-precision geospatial models of the terrain to analyze site conditions. Particular attention is paid to flight missi81

on planning with due regard for the terrain to improve the accuracy of the data required for further mine surveying.

Keywords: aerial photography, unmanned aerial vehicle, geospatial model, digital terrain model

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ИССЛЕДОВАНИЕ СОСТОЯНИЯ ПРИБОРТОВОГО МАССИВА НА РАЗРЕЗЕ «ЭКОЛОГ» С ПРИМЕНЕНИЕМ АЭРОФОТОСЪЕМКИ

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Аннотация: В статье рассматривается использование аэрофотосъемки для мониторинга прибортового массива на разрезе «Эколог» с применением дрона «DJI Mavic 2 Pro». Целью исследования является создание высокоточных геопространственных моделей местности для анализа состояния объекта. Особое внимание уделено планированию полетной миссии, с учетом рельефа местности для повышения точности данных, необходимых для дальнейших маркшейдерских исследований.

Ключевые слова: аэрофотосъемка, беспилотный летательный аппарат, геопространственная модель, цифровая модель рельефа

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Introduction

The walls of quarries and open pits become unstable during mining operations, which requires constant assessment of their condition. Using of unmanned aerial vehicles for air photography to monitor open pit walls condition is necessary for solving mining operations problems in a timely manner. The purpose of air photographic survey carried out at Ekolog Open-pit Mine is acquisition of detailed images for the subsequent generation of geospatial models, with reference to which the main tasks will be completed:

1. Obtaining high-resolution images of the open pit edge based on a scheduled flight.
2. Ensuring data integrity and accuracy for subsequent analysis and digital models' generation.
3. Generation of site digital models to solve a wide range of practical problems.
4. Assessment of the adjacent rock mass condition at the open pit.

Materials and Surveying Methods

Equipment for work performance. Before starting the air photographic survey, there was carried out a comprehensive preparation, including the following stages.

Equipment selection. DJI Mavic 2 Pro drone equipped with TOPODRONE PPK surveying set was selected to perform air photography. TOPODRONE PPK surveying sets include multi-system L1/L2GNSS receiver of own design with a built-in inertial measurement unit (IMU), and three-axis gimbal for installing various payloads on drones. These sets ensure the geodetic survey performance with an accuracy of up to 5 cm in plan and in elevation without being required to use reference points. The present sets render possible to modify the drone for topographic mapping at a scale of 1:500, accurate measuring of fill and cut quantity, designing and carrying out if other survey works [3].

DJI Mavic 2 Pro PPK drone has a number of advantages:

- highly detailed photos owing to a 20-megapixel camera, which makes it stand out among surveying drones;
- one of the most compact and high-performance devices, providing coverage of up to 30 hectares per 30 minutes flight;
- an increased case strength compared to other surveying drones in its class;
- operating in PPK (Post Processed Kinematic) mode that does not require an Internet connection;
- real-time correction of satellite signal errors at a distance of up to 25 km from the base stations;
- saving data in a memory card with no need of a wireless connection to the onboard GNSS receiver;
- automatic conversion of high-precision coordinates of photo points into a local coordinates system.

The surveying set for TOPODRONE DJI Mavic 2 Pro PPK drone, presented in Figure 1, includes TOPODRONE PPK multi-system L1/L2 GNSS receiver, removable L1/L2 GNSS antenna, GNSS receiver housing for installation on DJI Mavic 2 Pro, flexible flat cable for GNSS receiver connection to the drone board, and 16GB memory card for GNSS data recording [3].

DJI Mavic 2 Pro unmanned aerial vehicle (UAV) (Figure 2) is a compact, foldable drone designed for high-quality photo and video shooting. This model is equipped with a professional Hasselblad L1D-20C camera with HNCS technology used to provide 20-megapixel (4K) resolution. The camera has 1-inch matrix designed to enable increased light sensitivity (ISO 100–800) and low noise, making it perfect for shooting in low-light conditions [3].

In order to have sharper images, regardless of the lighting level, the camera is equipped with the controlled aperture (f2.8 - f11). In combination with High Dynamic Range (HDR) function, this aperture provides excellent detail in both bright and dark areas of the image.

Fig. 2. TOPODRONE DJI Mavic 2 Pro PPK /
Рис. 2. «TOPODRONE DJI Mavic 2 Pro PPK»

Technical characteristics of the drone are listed in Table 1.

Table 1 / Таблица 1

DJI Mavic 2 Pro PPK Characteristics /
Характеристики «DJI Mavic 2 Pro PPK»

Characteristic / Характеристика	Value / Значение
Survey area (per flight) / Площадь съемки (один полет)	30 ha (from 80 m altitude)
Flight duration, min / Время полета, мин	25-30
Allowable wind speed, m/s / Допустимая скорость ветра, м/с	up to15
Type of GNSS receiver / Тип ГНСС приемника	L1/L2
Satellites / Спутники	GPS, GLONASS, BeiDou, Galileo, SBAS
Number of channels / Каналы (количество)	184
Survey frequency, Hz / Частота работы, Гц	10
Data accuracy (x, y, z), cm / Точность данных (x, y, z), см	3-5
Camera resolution, MP / Разрешение камеры, МП	20
Air temperature, °	-15…+40

Flight planning. The flight route is planned taking into account the open-pit area. To achieve high quality air photography, a flight mission project has been developed in DJI GS PRO software tool, which determines the flight route (Figure 3).

Fig. 1. Surveying set elements of DJI Mavic 2 Pro PPK drone /
Рис. 1. Комплектация геодезического комплекта дрона «DJI Mavic 2 Pro PPK»

Fig. 3. Flight mission planning in DJI GS PRO for Ekolog Open-pit Mine /
Рис. 3. Проект полетной миссии на разрезе «Эколог» в «DJI GS PRO»

This flight planner allows to flexibly configure all the necessary parameters of the flight task and takes due regard to the terrain, which ensures the most accurate and appropriate calculation of flight parameters. Once flight mission is developed, marking out of ground control points shall be next stage (marks Figure 4).

During photogrammetric processing, these marks serve as control points for assessing the accuracy of air photography survey, and are also used to improve the alignment and transformation of the surface model, ensuring global accuracy of up to 3-5 cm (along X, Y, Z coordinates). Marks are evenly spaced throughout the survey area with the same distance between them. After that, the project is loaded into GNSS receiver's (rover) memory for further installation of marks at the terrain during field survey.

Equipment preparation. Drone flight preparation procedure includes the following stages: drone integrity check, battery charging, test flight execution, flight mission project development, creation of ground control points placement diagram and GNSS equipment inspection. The batteries of drone, remote control and associated mobile device shall be fully charged before starting the flight. When the drone is prepared, GNSS equipment shall be configured, including calibration and balancing. Method of communication between the receiver and the base station is configured to obtain differential corrections and conduct GNSS measurements [4].

Air photography survey was performed in accordance with the established flight plan. Main flight parameters:

1. Flight altitude was 160 m, and maximum spatial resolution was 3.95 cm/pixel at that altitude, which was suitable for works at scales of 1:500 - 1:1000.

2. Flight speed was 8.4 m/s; frame rate was 2.5 s; longitudinal and transverse overlap values were 85% and 70% respectively; the survey was carried out in the planned mode with the camera position vertically down that is transversely to the earth surface.

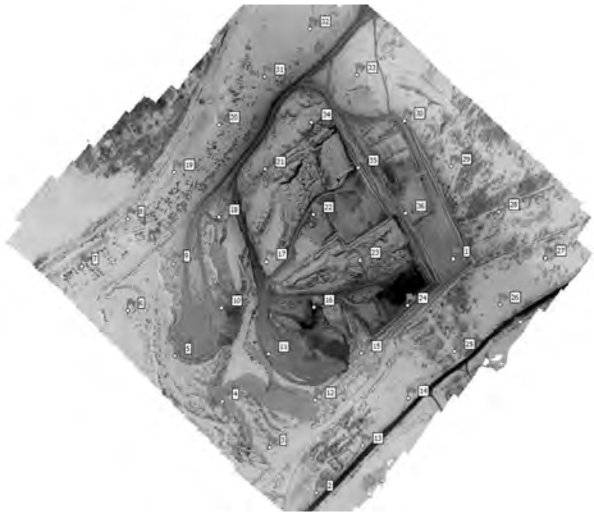

Fig. 4. Ground Control Points Marking out Project for Ekolog Open-pit Mine /
Рис. 4. Проект наземных опознавательных знаков на разрезе «Эколог»

As a result of the flight, there were obtained many images covering the entire area of Ekolog Open-pit Mine, which made it possible to have a complete set of data for processing.

Processing and Interpretation of Data Obtained

Agisoft Metashape program was used to process the data obtained during air photography survey. This tool allows for efficient processing of air photographs created with UAVs and their transformation into highly-precise geospatial information. Based on the obtained images, there was performed photogrammetric processing, which resulted in the creation of point clouds and 3D terrain models. Agisoft Metashape generates geospatial data that provides an accurate and detailed representation of topographic surface and objects. This data can be used for further analysis, including volume calculation, monitoring of topographic variations and other mine surveying tasks [5].

Semi-Global Matching (SGM) technology applied in 3D reconstruction and photogrammetry, was used to create a dense point cloud (Figure 5).

SGM uses a balance between the accuracy of global methods and the computational efficiency of local methods. SGM is widely used in applications for generating 3D terrain models, processing data from drones and mapping systems.

Fig. 5. Dense point cloud / *Рис. 5.* Плотное облако точек

Dense point cloud is used for designing elevation maps, which are digital terrain models (DTM) (Figure 6).

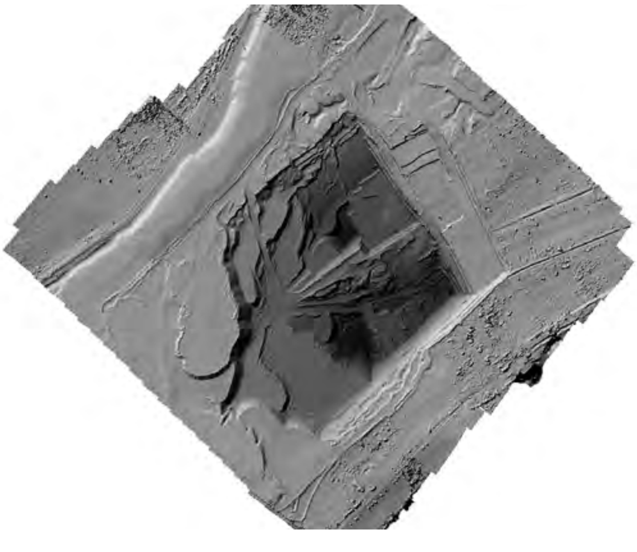

Fig. 6. Digital terrain model / *Рис. 6.* Цифровая модель рельефа

There was made a digital terrain model with the specified parameters: resolution of 9.4 cm per pixel, and point density of 113 points per square meter.

Agisoft Metashape software makes possible to visualize the surface model as a regular grid of elevation values, which ensures high accuracy of the data obtained.

The tile model was built based on the dense point cloud (Figure 7).

Tile model is a simplified three-dimensional terrain model where each point of the model corresponds to a specific point on the real earth surface [5]. Tile model can be generated based on a point cloud or depth maps, and texturing of hierarchical tiles is performed using source images that ensures visual data and real surface correspondence. At the final stage, the model is exported to the desired format that allows to use it in various applications, such as cartography and environmental studies. Quality control and elimination of possible artifacts complete the process, ensuring high quality of the final model [5].

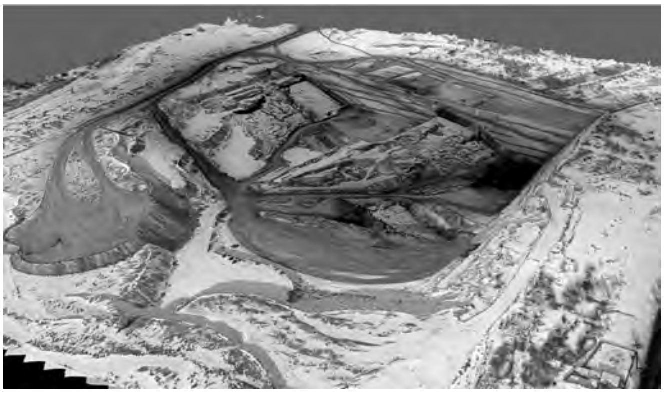

Fig. 7. Tile model / *Рис. 7.* Тайловая модель

The final stage of photogrammetric processing is orthophotomap generation (Figure 8). Metashape program projects the original photographs onto the surface of a polygonal model or digital terrain model (DTM) to generate an orthophotomap. Depending on the selected projection method, the images are converted into a flat object image.

Using original photographs helps to create a high-resolution image. An orthophotomap is designed to obtain a detailed object image.

In case of variations in lighting conditions during the survey, it is recommended to use a color correction tool to equalize brightness and color balance before orthophotomap generating [5].

The result of orthophotomap generating is shown in Figure 8.

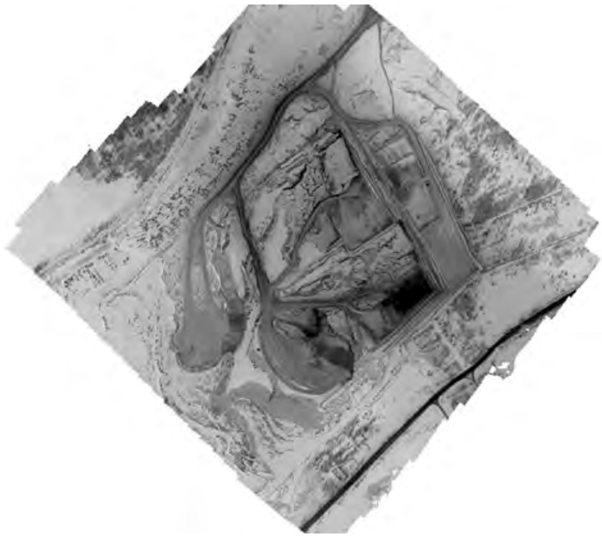

Fig. 8. Orthophotomap / *Рис. 8.* Ортофотоплан

After photogrammetric data processing in Agisoft Metashape software, it is possible to generate a report that can be exported in PDF format for further analysis. [5]. The report includes basic information about the source data, processing results, and accuracy assessment (Figure 9, Table 2).

In Figure 9, the error in Z is shown by the color of ellipse. Errors in plan are displayed as the shape of ellipse. The calculated positions of photography points are marked with black dots.

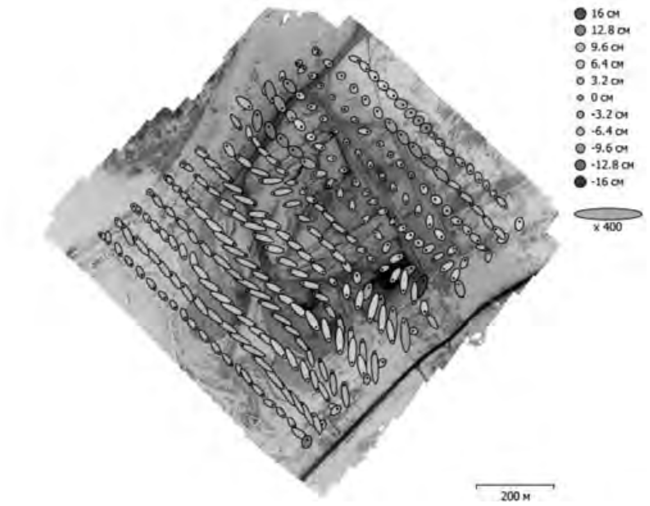

Fig. 9. Calculated positions of photographing centers and accuracy assessment / *Рис. 9.* Рассчитанные положения центров фотографирования и оценка точности

Table 2 / Таблица 2

Mean error in photographing centers coordinates / Средняя ошибка по координатам центров фотографирования

Error, X (cm) / Ошибка, X (см)	Error, Y (cm) / Ошибка, Y (см)	Error, Z (cm) / Ошибка, Z (см)	Error XY (cm) / Ошибка XY (см)	Total error (cm) / Общая ошибка (см)
5.07	5.56	4.87	7.52	8.96

Results obtained

When the air photography survey at Ekolog Open-pit Mine is processed in Agisoft Metashape, the resulting geospatial data, such as point clouds and 3D terrain models, can be exported to various formats, including .obj, .las and .tif. The data can then be integrated into various programs, such as Maptek I Site Studio (Figure 10).

Maptek Point Studio program can generate wireframe models of earth surface and man-made objects and hereon perform further analysis of the resulting digital model, for example, surveying calculations.

Thus, Agisoft Metashape ensures accurate recording of topographical surface and objects, and the selected software such as Maptek I Site Studio provides tools for further processing, analysis and monitoring of mining sites changes. This permits to effectively use the obtained data for various purposes, from modeling to deformation analysis.

As part of the work performed, there was generated a wireframe model of Ekolog Open-pit Mine topographic surface (Figure 11).

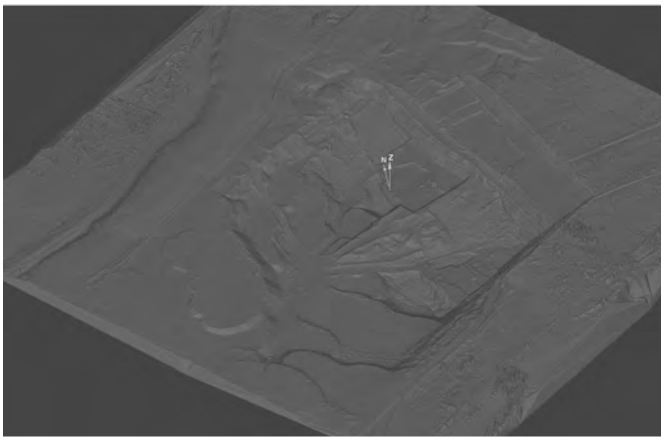

Fig. 11. Wire-frame model of Ekolog Open-pit Mine in Maptek Point Studio program / *Рис. 11.* Каркасная модель разреза «Эколог» в ПО Maptek Point Studio

Findings

An important and promising area of application of earth surface and man-made objects wireframe models is monitoring of displacements and deformations, determining the stable state of the objects under study.

The open-pit adjacent rock mass is a complex object in

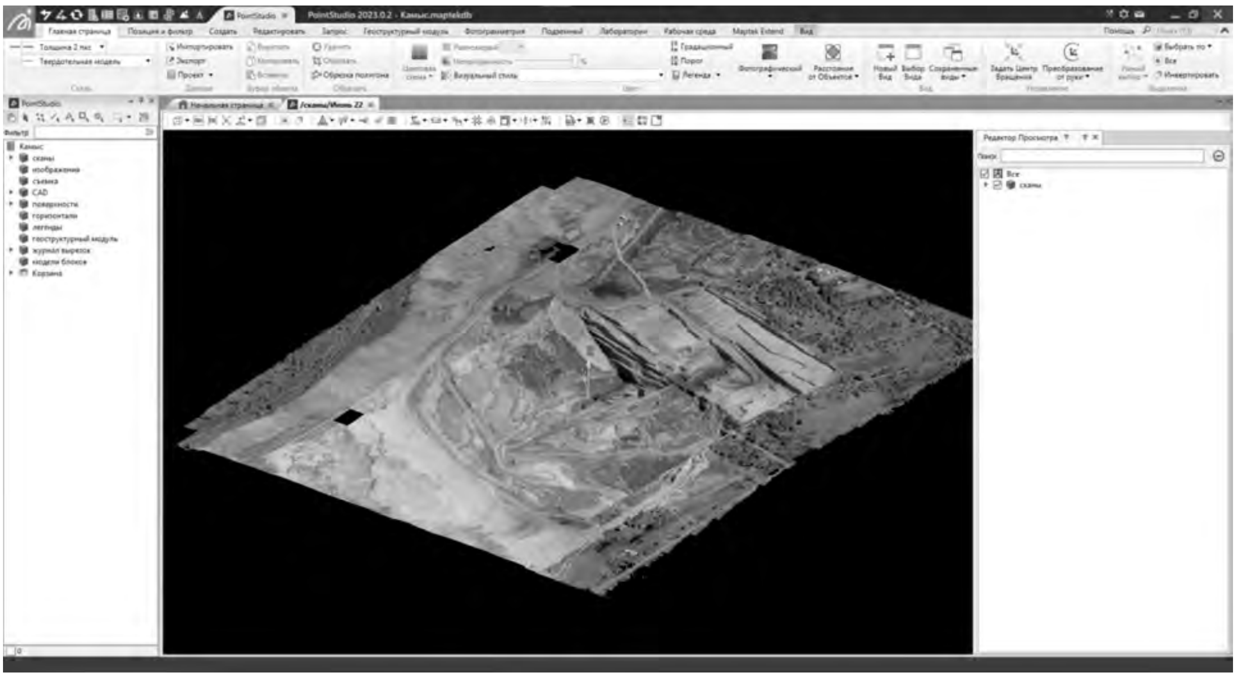

Fig. 10. Maptek Point Studio program interface / *Рис. 10.* Интерфейс программы Maptek Point Studio

geotechnical context, and subject to constant monitoring. The danger of negative impact of various factors attends on the open-pit slopes at all stages of the mine life: construction, operation and mined-land reclamation. Geotechnical monitoring was associated with a high proportion of manual labor, low productivity of measuring instruments and lack of effective means for processing, storing, analyzing and managing long-term observation data.

The implementation of geotechnical monitoring of the adjacent rock mass condition at Ekolog Open-pit Mine using air photography data is a progressive technical solution based on modern digital technologies. Air photographic survey makes it possible to monitor the condition of benches, groups of benches and open-pit walls on a timely basis, to identify poor conditions in due time and to prevent emergency situations.

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