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THE USE OF DIGITAL TECHNOLOGIES IN THE DEVELOPMENT OF MINERAL DEPOSITS

ПАЙДАЛЫ ҚАЗБАЛАР КЕН ОРЫНДАРЫН ИГЕРУ КЕЗІНДЕ ЦИФРЛЫҚ ТЕХНОЛОГИЯЛАРДЫ ҚОЛДАНУ

ПРИМЕНЕНИЕ ЦИФРОВЫХ ТЕХНОЛОГИЙ ПРИ РАЗРАБОТКЕ МЕСТОРОЖДЕНИЙ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

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unmanned aerial
vehicles, quarry,
reference points,
identification,
aerial photography,
height map, the digital
model.

ABSTRACT

The relevance of the topic is due to the increasing need of the mining industry for prompt and highly accurate spatial data acquisition for mining operations and safety. The article presents a methodology for creating a digital model of the earth's surface in the development of deposits using unmanned aerial vehicles (UAVs). Modern technologies of aerial photography, data processing and construction of high-precision digital models of the Earth's surface are considered. The stages of aerial photography and image processing are described, allowing minimizing errors and improving the accuracy of model construction. A technique is proposed to improve the accuracy of models by optimizing the flight parameters of UAVs and calibrating sensors. The results obtained can be applied to optimize mining operations and geodetic monitoring of the state of man-made facilities and environmental control.

Түйінді сөздер:

ұшқышсыз ұшу
аппараттары, ашық
кеніш,
тірек нүктелері,
сәйкестендіру
белгілері,
аэрофототүсірілім,
биіктік картасы,
ортофотоплан,
сандық модель.

ТҮЙІНДЕМЕ

Тақырыптың өзектілігі тау-кен өндірісінің тау-кен жұмыстарын бақылау және қауіпсіздікті қамтамасыз ету үшін кеңістіктік деректерді жедел және жоғары дәлдікпен алуға қажеттілігінің артуына байланысты. Мақалада пилотсыз ұшу аппараттарын (ҰҰА) пайдалана отырып, кен орындарын игеру кезінде жер бетінің цифрлық моделін құру әдістемесі келтірілген. Аэрофототүсірілімнің, деректерді өңдеудің және жер бетінің жоғары дәлдіктегі цифрлық модельдерін құрудың заманауи технологиялары қарастырылған. Аэрофототүсірілім, кескінді өңдеу өндірісінің қадамдары сипатталған, бұл қателіктерді азайтуға және модель құру дәлдігін арттыруға мүмкіндік береді. Ұшқышсыз ұшу параметрлерін оңтайландыру және сенсорларды калибрлеу арқылы модельдердің дәлдігін арттыру әдісі ұсынылған. Алынған нәтижелер тау-кен жұмыстарын оңтайландыру және техногендік объектілердің жай-күйіне геодезиялық мониторинг жүргізу және экологиялық бақылауды жүзеге асыру үшін қолданылуы мүмкін.



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Ключевые слова:

беспилотные
летательные аппараты,
карьер,
опорные точки,
опознаки,
аэрофотосъемка,
карта высот,
ортофотоплан,
цифровая модель.

АННОТАЦИЯ

Актуальность темы обусловлена возрастающей потребностью горно-добывающей отрасли в оперативном и высокоточном получении пространственных данных для контроля горных работ и обеспечения безопасности. В статье приведены методика создания цифровой модели земной поверхности при разработке месторождений с использованием беспилотных летательных аппаратов (БПЛА). Рассмотрены современные технологии аэрофотосъемки, обработки данных и построения высокоточных цифровых моделей земной поверхности. Описаны этапы производства аэрофотосъемки, обработки изображений, позволяющие минимизировать погрешности и повысить точность построения моделей. Предложена методика повышения точности моделей за счёт оптимизации параметров полёта БПЛА и калибровки сенсоров. Полученные результаты могут быть применены для оптимизации горных работ и проведения геодезического мониторинга за состоянием техногенных объектов и осуществления экологического контроля.

INTRODUCTION

The use of unmanned aerial vehicles (UAVs) in field development has become a standard practice, providing significant improvements in safety and accuracy.

The relevance of the topic is due to the increasing need of the mining industry for prompt and highly accurate spatial data acquisition for mining operations and safety. Traditional methods of geodetic tracking are characterized by high labor intensity and significant costs. The use of unmanned aerial vehicles (UAVs) opens up new opportunities for improving the efficiency of geodetic monitoring. The use of UAVs is driven by global trends in the digitalization of industry and the need to improve the efficiency, safety and environmental friendliness of mining enterprises. Methods for constructing digital models of the Earth's surface in the development of deposits using unmanned aerial vehicles, including the processes of mission planning, obtaining aerial photography data, their photogrammetric processing and spatial analysis in geoinformation systems. The widespread introduction of UAVs is in demand, since traditional methods of surveying have a number of significant limitations that are successfully overcome with the help of unmanned technologies.

The main aspects of relevance:

- cost-effectiveness: the use of UAVs can significantly reduce the time and cost of field work, which is very important for operational planning and production management;
- increased safety: quarries are dangerous facilities. The use of drones endangers the lives and health of employees, allowing them to monitor remote and dangerous areas from a distance;
- high accuracy and detailed data: digital models based on aerial photography from unmanned aerial vehicles provide accurate and up-to-date information about the volume of rock excavation, the remains of raw materials, the condition of the sides and dumps, which is not available using outdated methods;
- decision-making efficiency: regular and rapid receipt of up-to-date 3D models allows mining engineers and managers to quickly respond to changes, adjust production plans and optimize logistics;
- environmental control: factual data helps to monitor compliance with design decisions, minimize negative environmental impacts, and effectively carry out remediation work;
- meeting the trends of digital transformation - the introduction of unmanned technologies is a key element in creating "digital twins" of enterprises («digital twin») and integrating data into common automated management systems of the mining industry (Petrov A.A., Zhdanko D.F. 2022;

Traditional methods of geodetic tracking are characterized by high labor intensity and significant costs. The use of unmanned aerial vehicles (UAVs) opens up new opportunities for improving the efficiency of geodetic monitoring. The use of UAVs is driven by global trends in the digitalization of industry and the need to improve the efficiency, safety and environmental friendliness of mining enterprises. Methods for constructing digital models of the Earth's surface in the development of deposits using unmanned aerial vehicles, including the processes of mission planning, obtaining aerial photography data, their photogrammetric processing and spatial analysis in geoinformation systems (Kolesatova O.S., Krasavin A.V. 2020). The widespread introduction of UAVs is in demand, since traditional methods of surveying have a number of significant limitations that are successfully overcome with the help of unmanned technologies.

The subject of the study: Methods for constructing digital models of the Earth's surface in the development of deposits using unmanned aerial vehicles, including the processes of mission planning, obtaining aerial photography data, their photogrammetric processing and spatial analysis in geoinformation systems.

The purpose of the study. Development and testing of a comprehensive methodology for constructing a digital model of the Earth's surface using UAVs in the development of open-pit mineral deposits using the example of the Koktaszhal quarry.

The use of unmanned aerial vehicles (UAVs) in quarries has become a key factor in optimizing mining operations. The main advantages include:

1. Accuracy and speed of surveying work

Data collection is 5-10 times faster: Traditional ground-based measurement methods take days, while drones allow you to collect career data in a few hours.

High detail: The use of lidars and high-resolution cameras allows you to create 3D models («digital twin») with an accuracy of several centimeters, which is critical for calculating volumes in warehouses and workings.

2. Increased security (Human-Out-of-the-Loop)

Remote monitoring of hazardous areas: Drones inspect high ledges, sides of quarries and areas after explosions, eliminating the need for personnel in places at risk of collapse.

Injury reduction: Remote data collection replaces the dangerous climbing of experts on dumps and steep slopes.

3. Real-time monitoring and control

Operational progress monitoring: Drones allow you to monitor daily the implementation of mining plans, compliance with design contours and the condition of roads for dump trucks.

Autonomy (Drone-in-a-Box): automatic stations have been actively introduced recently, where drones take off on schedule and charge without an operator, providing round-the-clock monitoring.

4. Ecology and Audit (ESG)

Environmental monitoring: Drones are used to take air samples, monitor dust and the condition of tailings ponds, ensuring transparency of environmental reporting.

MATERIALS AND RESEARCH METHODS

Large-capacity mining enterprises are usually characterized by high speed of movement of the faces, rapid variability of the boundaries of the dump complex and tailings facilities, ore warehouses and, often, the simultaneous existence of two, three or more construction sites. In this case, it is difficult to carry out operational control over all facilities by traditional means. To increase productivity, it is possible to use UAVs.

Surveying a quarry using a UAV is a modern method that allows you to obtain up-to-date data on the state of quarries, landfills and the surrounding area, create three-dimensional terrain

models, calculate mining volumes and control production. UAVs equipped with cameras and other equipment provide high accuracy and efficiency, replacing or complementing traditional shooting methods.

The development of a methodology for creating a digital model of the earth's surface in the development of deposits using UAVs for each research object is developed individually, taking into account the specifics. To achieve this goal, it is necessary to solve the following tasks:

- to study the theoretical foundations of building a digital model of the Earth's surface;
- to analyze UAV technologies and methods of their application;
- identification and evaluation of the stages of building a digital model of the Earth's surface;
- to show the practical application of the digital model in the development of deposits by analyzing the results.

The reliability and completeness of the information received reduces operational risks and supports technological and managerial decision-making. The ability to transmit data in real time makes it possible to visually monitor even remote objects at all stages of operation (Buzalo N.A., Kundryutskov D.N., 2021; Buzalo N.A., Kundryutskov D.N., Ponomarev R.R. 2022).

A complex for geodetic aerial photography based on an upgraded DJI Phantom 4 PRO quadcopter with an onboard geodetic RTK GNSS receiver (RTK/PPK image center coordinates determination) and a high-performance removable spiral-type GNSS antenna (Figure. 1).



Figure 1. DJI Phantom 4 RTK geodetic quadcopter

Note – compiled by the authors

The operation of the onboard scanning navigation unit is based on the well-established interaction of the GNSS satellite navigation system with the inertial system in real time. Depending on the required shooting accuracy, the scanner performs from two to several dozen measurements of laser reflections per square meter of terrain. Due to the high density of points and multiple reflections of the laser beam from the earth's surface, the ALS technology makes it possible to obtain a high-precision digital relief model (DEM), including man-made objects, buildings, structures and engineering communications (Smith M.W., Carrivick J.L., Quincey D.J., 2018; Bogdanov K.V., Beketova E.B., 2019).

Spatial characteristics based on the data obtained with the help of UAVs are used to monitor the state of natural and man-made objects. Unmanned aerial vehicles are used to solve geodetic problems and geomonitoring and subsequent spatial modeling, which is part of geodetic or geoinformation support. Currently, there are three main applications of UAVs: geodata collection, emergency support in emergency situations, regular geomonitoring or geotechnical monitoring (Cun Zhang, Yixin Zhao, Xiang He, Junting Guo., 2021; Chao Liu, Jingxiang Gao, Jian Wang, Feng Zhou., 2018).

The use of UAVs is most affordable in cases where the development of a mineral deposit is carried out in an open-pit manner. Monitoring of deformations of the earth's surface, the condition of quarries, dumps, mineral depots, tailings dumps and adjacent territories is relatively simple. Currently, the use of unmanned aerial vehicles (UAVs) in the development of mineral deposits makes it possible to solve a wide range of applied tasks in geodesy and surveying, such as 3D modeling; quarries and the earth's surface; monitoring the condition of rock dumps and adjacent zones; creating a geodetic base for deposits; surveying mined areas; operational control over compliance with the mining plan; calculation of the amount of work on stripping and extraction; creation of the basis for the remediation plan upon completion of the project (Moshood Onifade, John Adetunji Adebisi, Amtenge Penda Shivute, Bekir Genc. 2023).

The main advantage of using digital aerial photography at the same time is to obtain a sufficient amount of object data, which in turn makes it possible to quickly and easily determine the location of both real and rather complex and inaccessible objects located on the earth's surface. The camera positions and image overlap are shown in figure 2.

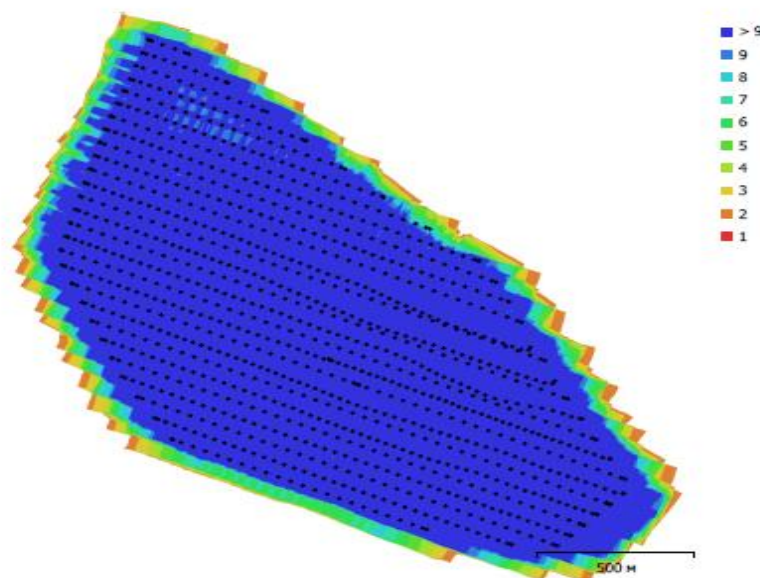


Figure 2. Camera positions and image overlap

Note – compiled by the authors

A series of UAV flights is carried out on pre-arranged routes. When creating a flight design, the altitude and flight path are selected depending on the required accuracy of the model and the characteristic features of the quarry (depth, area dimensions) and the relief of the surrounding area.

The DJI Phantom 4 RTK quadcopter for shooting is launched from a pre-calculated flight altitude, which varied depending on the size of the quarry and the shooting tasks (usually from 100 to 150 meters). All images were captured with an overlap of 80% in both axes to further create an orthophotoplane (Oleh Anisimov, Nataliia Bariatska, Nina Safronova, Oleksii Cherniaiev. 2026). During the shooting, the battery level of the quadcopter was monitored and stable communication with the control panel was provided to receive real-time video and monitor the quality of the images.

The location of the reference and control points and the error assessment of the Koktaszhal quarry are shown in figure 3.

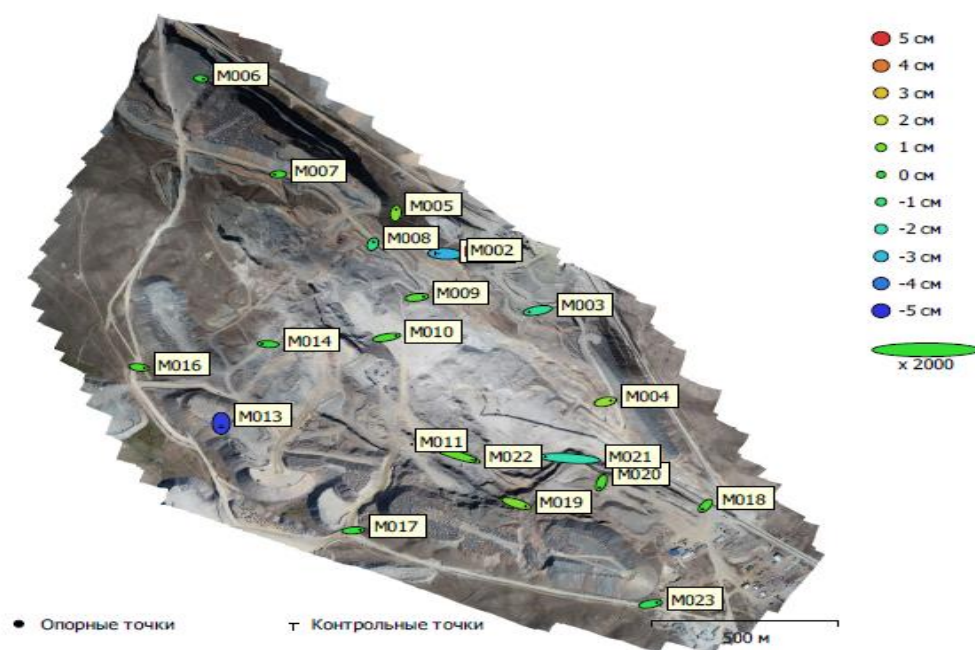


Figure 3. Position of reference and control points and error estimation

Note – compiled by the authors

Data on determining the position of reference and control points are given in tables 3-4.

Table 1. Data on reference points

Title	Mistake, X (cm)	Mistake, Y (cm)	Mistake, Z (cm)	General, (cm)	Photo (pix)
M001	1,62489	0,114185	-0,476511	1,69716	0,386 (12)
M003	-2,31448	-0,551039	-1,42387	2,7727	0,327 (14)
M004	1,45701	0,412592	1,4477	2,09498	0,197 (25)
M005	0,115998	1,35024	1,10869	1,75094	0,271 (14)
M006	0,712291	-0,133807	-0,0967793	0,731183	0,207 (19)
M007	-0,929186	-0,0701609	0,240808	0,962444	0,223 (16)
M008	0,222103	0,765917	-1,15856	1,40649	0,229 (16)
M009	1,81141	0,284364	0,5518	1,91482	0,211 (19)
M010	2,53903	0,59777	0,296298	2,62522	0,130 (29)
M014	-1,63774	0,138146	-0,0470997	1,64423	0,218 (14)
M016	1,41689	-0,237908	0,340429	1,4765	0,201 (13)
M017	1,83857	0,190183	-0,187609	1,85788	0,155 (15)
M018	-0,831912	-1,15609	0,334245	1,46299	0,209 (27)
M019	2,50556	-0,999277	1,086631	2,908	0,122 (22)
M020	-0,515694	-1,73086	0,361422	1,84186	0,167 (24)
M021	-6,53175	0,572347	-1,85857	6,8151	0,180 (37)
M023	1,78806	0,455379	-0,586705	1,93617	0,197 (25)
General	2,20225	0,741045	0,866217	2,479979	0,209

Note – compiled by the authors

Table 2. Data on control points

Title	Mistake, X (cm)	Mistake, Y (cm)	Mistake, Z (cm)	General, (cm)	Photo (pix)
M001	-2,60828	0,133602	-3,13116	4,07739	0,348 (10)
M003	0,00536101	-1,50441	-4,8499	5,07787	0,153 (14)
M004	4,993994	-2,03979	0,644095	5,38318	0,196 (24)
General	3,22522	1,46536	3,35363	4,87813	0,225

Note – compiled by the authors

After the survey was completed, all the data was uploaded to the processing system to create a 3D model of the quarry, an orthophotoplane, and contour maps. The processed images and models allow not only to assess the current state of the quarry, but also to plan further developments and changes, such as the volume of mining, erosion analysis and other geodetic work.

THE RESULTS AND THEIR DISCUSSION

The processing of API materials is fully automated and is carried out using Agisoft PhotoScan Pro software, which is one of the modern photogrammetric technologies. To process the data, it is necessary to set the coordinates of the reference points, then the program automatically determines the connecting points in adjacent images and equalizes them to the specified reference points (Sebastián Granados-Bolaños, Adolfo Quesada-Román, Guillermo E. Alvarado, 2021). The location of the reference and control points and the error assessment of the Koktaszhal quarry are shown in figure 3.

Agisoft PhotoScan Pro software allows you to create a high-precision three-dimensional terrain model based on aerial photography data, and then generate an orthophotoplane and an altitude matrix based on the resulting model. A height map can be built based on data from a dense point cloud or a polygonal model. It is recommended to use dense point cloud data as the source to obtain more accurate results; also, in this case, the construction of a polygonal model is not required, which reduces the total processing time. The height map of the Koktaszhal quarry is shown in figure 4.

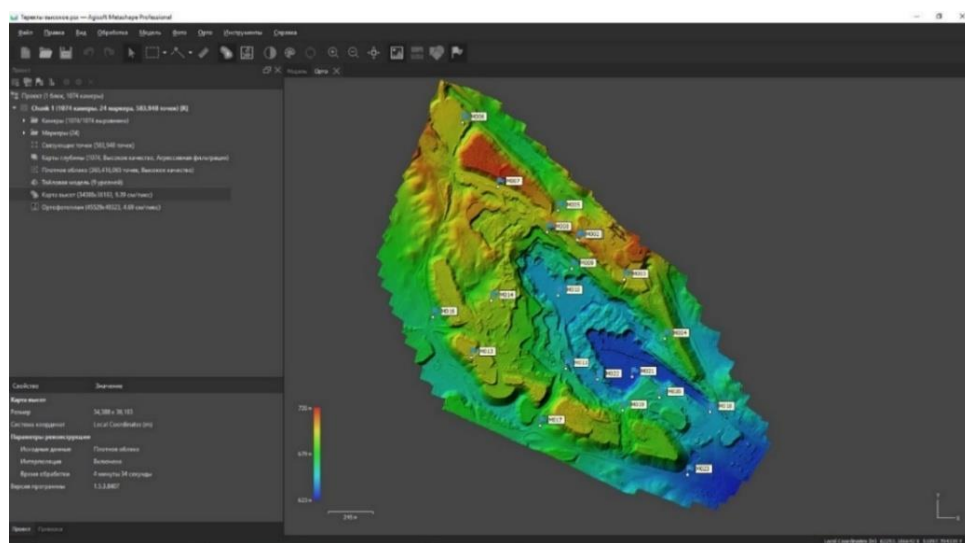


Figure 4. Height map

Note – compiled by the authors

The use of unmanned aerial vehicles when performing geodetic surveys makes it possible to quickly obtain orthophotoplanes, three-dimensional relief models and digital models of the Earth's surface, ensuring accuracy comparable to the results of ground-based methods. The use of unmanned technologies in the development of mineral deposits is particularly relevant, where it is necessary to frequently update data on the state of the relief, control the volume of stripping and mining operations, as well as control the stability of slopes and dumps (Nakata, Yasutaka, Iwasaki, Kenta, Shimoda, Seiji. 2023).

The orthophotoplane of the quarry surface is a photographic image of the quarry surface that is orthogonally projected onto a plane. The orthophotoplane allows you to obtain an accurate, scaled and geographically linked image of the quarry surface, which can be used for various purposes such as monitoring, planning and geodetic work. The orthophotoplane of the surface of the Koktaszhal quarry is shown in figure 5.

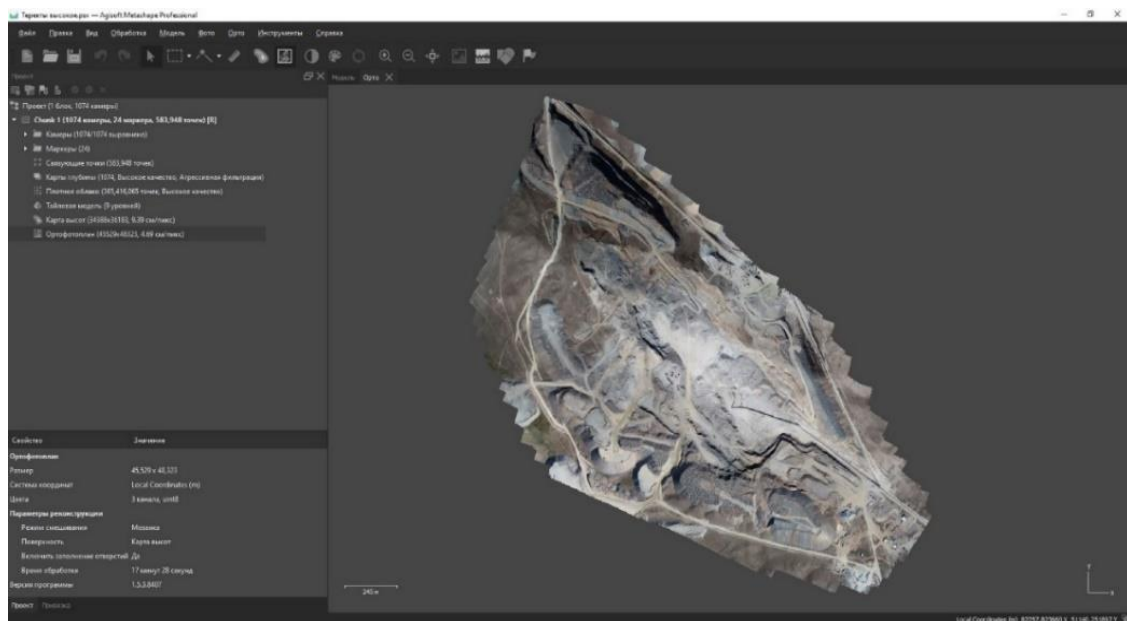


Figure 5. The orthophotoplane of the Koktaszhal quarry

Note – compiled by the authors

Using an orthophotoplane, a number of tasks can be solved:

- monitoring the condition of the quarry;
- geodetic surveys;
- deposit development design and planning;
- environmental monitoring;
- drawing up cadastral plans;
- assessment and calculation of mining volumes;
- creation of a 3D model of a quarry and a digital relief model (DEM).

The end result of API data processing is the construction of a digital terrain model (DEM). DEMS obtained from UAVs are a qualitative basis for creating the necessary accounting documentation for geodetic, surveying and geotechnological services of mining enterprises and are one of the types of accounting documentation submitted to regulatory authorities (Gerke M, et al., 2016). The calculated DEM of the Koktaszhal quarry is shown in figure 6.

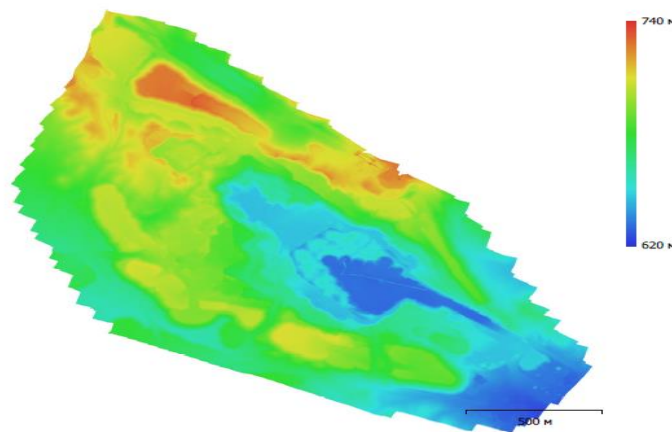


Figure 6. Digital model of the Kokstal quarry

Note – compiled by the authors

It should be noted that the geodetic monitoring area includes not only mining areas, but also adjacent territories located in close proximity.

During the exploration and development of mineral deposits, a fairly large amount of information accumulates: geological documents of exploration workings, test data, results of geophysical, geochemical studies, etc. Next, information is being developed to create geological maps, sections, each horizontal plan, projections of ore bodies, and other issues. For operational planning of mining operations at mining enterprises and solving various technological issues, monitoring the stability of slopes of ledges and sides of quarries, it is necessary to create a digital model of an open-pit mine. The 3D digital model of the Koktaszhal quarry based on the survey results is shown in the figure 7.

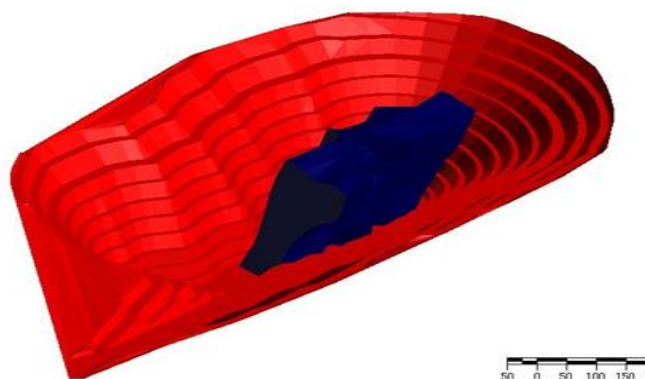


Figure 7. 3D digital model of the Koktaszhal mine

Note – compiled by the authors

Digital surface models obtained using UAV technology are based on surface studies and will be much more complete. The use of UAVs is more economical and faster than ground-based methods, and the accuracy results are usually closer to the results of laser scanning. In addition, with the help of modern software, effective functions are widely provided that are available for improving mining operations (Igemberlina M., Tuyakbay A., Estaeva A. 2020).

Thus, thanks to the development of technology and technology, it has become possible to use modern geodetic equipment to monitor the condition of man-made objects. Currently, UAVs are one of the most advanced technologies.

CONCLUSION

The use of drones has shown a fairly high efficiency in solving the problems of geomechanical and geodetic monitoring, long-term forecasting of the process of displacement of the Earth's surface and the adoption of timely measures to ensure the safety of mining operations.

Summing up, it should be noted that in mining enterprises, for operational planning of mining operations and solving technological issues, as well as for monitoring the stability of the slopes of ledges and sides of the quarry, it is necessary to create a digital model of an open mine.

The main directions and prospects of development include:

- full automation and autonomy - UAVs independently perform scheduled missions (for example, daily career flight) without human intervention, from takeoff to landing and data transmission;

- IoT integration: drones become part of the ecosystem of the Internet of Things as a whole (IoT) in the enterprise, communicating with other equipment (dump trucks, excavators, sensors) in real time;

- extended range of applications - underground work: development of special drones for inspection of underground workings, mines and tunnels without GPS signal. This allows you to check the condition of the roof, ventilation systems and communications in hard-to-reach places.

Geological exploration: the use of drones with lidar, hyperspectral and multispectral cameras for more accurate and rapid exploration of deposits and mapping geological structures;

- predictive analytics: Artificial intelligence analyzes 3D models to predict the stability of ships and conditions of open mines or potentially dangerous situations such as landslides;

- automated accounting: Artificial intelligence can automatically calculate production and production volumes in warehouses with high accuracy, except for the human factor;

- increased flight time: Improved battery technology allows drones to operate longer and cover larger areas without frequent charging (Wang C., Shu Q., Wang X., Guo Bo, Liu P., Li Q., 2019).

The scientific novelty of the work is as follows:

1. New data has been obtained on the effect of aerial photography parameters from UAVs on the accuracy of digital models in field development conditions;

2. A methodology has been developed for geodetic monitoring of mining operations using unmanned technologies, taking into account the features of the quarry relief and accuracy requirements;

3. An algorithm for evaluating the quality of digital models is proposed, which increases the reliability of monitoring the condition of deposits.

The practical significance lies in the fact that the results of the study can be used to improve the efficiency of geodetic monitoring during open-pit mining. The methodology can be implemented in the practice of surveying services for monitoring mining operations, calculating production volumes, monitoring slope stability and land reclamation.

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