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Study of rock mass structural features based on laser scanning results

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ABSTRACT

Monitoring of pit slopes benches stability and pit walls plays the important role in the safety of mining operations. Slope stability assessment and risk management are mandatory to ensure safe and efficient operation of pits. Laser scanning technology is one of the base methods of geospatial data collecting for building of man-made objects models. Laser scanning is widely used in mining when performing survey work, measurements, monitoring, and studying structural features on the outcroppings of the rock mass. The article describes the technological chain: the collection of geospatial data, the processing of the obtained data with the construction of a terrain model and the further use of the resulting model to solve practical tasks. The choice of optimal laser scanning parameters should be based on the technological features of a pit, the technical characteristics of used equipment and scanning density required to solve the tasks. The article demonstrates the use of the obtained model for determining the necessary geometric parameters of the structural features of the rock mass to conduct kinematic analysis of potential bench failures at the object of study. Based on the results of kinematic analysis, recommendations were developed for further mining operations and potential bench failures risks reducing. The proposed technology can be used and adapted for laser scanning, followed by the construction of a terrain model at various mineral deposits to solve a wide range of tasks and ensure the safety of open-pit mining. Due to the inclusion of laser scanners in the register of measuring instruments in Kazakhstan, high reliability of measurement accuracy is ensured. The technology allows both to obtain generalized data on the sides of the quarry, as well as detailed scans of individual ledges. A significant advantage is the automatic generation of a point cloud during scanning, which reduces in-house processing.

Keywords: laser scanning, geospatial data, digital terrain model, kinematic analysis, pit, rock mass structure.

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Introduction

Scientific and technological progress in the field of digital technologies has led to the improvement of methods for studying rock mass in the mining industry. This made it possible to take into account a larger number of parameters for constructing structural models that are as close as possible to the actual mining and geological situation of the studied field [[1], [2], [3]]. Using three-dimensional modeling of deposits has significantly influenced the entire mining process and the adoption of design decisions. The most important stage in creating models of a rock mass is the collection of initial data [[4], [5]]. Ground-based laser scanning is used for subsequent modeling of a pit and its individual elements. Pit slopes are potentially dangerous objects. The use of laser scanning makes it possible to remotely obtain data on the structure of rock outcroppings on the surface of the open pit walls of pits, which ensures the safety of personnel conducting measurements. The efficiency of the work is an important advantage of this technology. Based on the constructed models, a wide range of applied mining tasks can be solved at a pit [[6], [7], [8]].

The problem of quickly performing three-dimensional surveys to account for mining, monitor the condition of rock slopes, and control reserves in mining requires a lot of effort and resources, placing special requirements on measuring instruments. Aerial photography and laser scanning technologies are suitable for the effective solution of these tasks. Ground-based laser scanning is superior to aerial photography in terms of accuracy and detail, especially in the study of complex geometric shapes and small cracks. However, aerial photography is more convenient for covering large areas and operational surveys, but is inferior in terms of measurement accuracy and detail of the resulting model [[9], [10]].

The article describes in stages the methodology of laser scanning for geospatial data collecting, subsequent processing of the obtained data with the construction of a digital terrain model, the study of structural features and their parameters. Kinematic analysis was also carried out to assess the probability of landslides.

The object of the study was the potentially dangerous section of the northern open pit wall of Chiganak pit of the barite deposit (Zhambyl region, Republic of Kazakhstan). The engineering and geological conditions of Chiganak deposit are classified as difficult. The geological structure of the deposit is characterized by a large tectonic disturbance (the presence of disjunctive and plicative disturbances) and the occurrence of rocky and semi-rocky dislocated fractured rocks with the presence of crushing and weathering zones.

Experimental part

The study of the elements of rock mass structure always begins with the selection of the scanning area where there are clearly visible structural elements on the outcroppings. To set and coordinate the position of the scanner, it is necessary to determine at least two solid points for cross-surveying the pit area under study and creating an overlap of scans.

The scanning density (scanning grid) is determined by the assigned tasks, the solution of which will be performed according to the resulting model. To achieve the stated density of the point cloud, even in blind spots, an increase in scanning density due to overlapping scans will not be taken into account. The initial data for calculating of the optimal parameters of the scanner installation are the size of the investigated section of the open pit wall of the pit, the required density of the point cloud, the technical characteristics and equipment of the scanner, as well as the technological features of the pit that affect the installation of the scanner.

To study the structural features of the potentially dangerous section of the northern open pit wall of Chiganak field pit, a minimum scanning density of 10*10 mm was adopted. Based on this, the optimal installation parameters of the Leica HDS 8800 3D scanner were determined. To obtain scans with an overlap of at least 80% and the scanning grid density of 10*10 mm, the distance between solid points was 35 meters, with the scanning range of about 30 m (Figure 1).

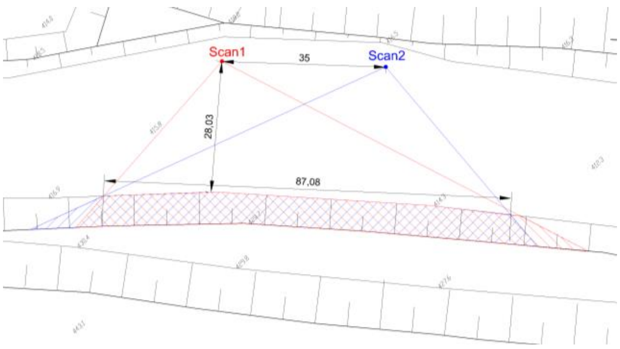

Figure 1 - Scheme of ground laser scanning of the studied section of the pit benches

The Leica HDS8800 scanner, which is a comprehensive laser scanning surveying system specially designed for use in the mining industry, was used to perform the study. The Leica HDS8800 has adaptive scan density and can scan in five modes. In scanning mode No. 16, a high level of detail of 21 mm is achieved at a distance of 100 mm, which can be increased by reducing the distance to the scanned object. The dependence of the scanning density on the selected mode and the scanning range from 14 to 30 meters is calculated (Table 1).

Table 1 - The dependence of the scanning density on the selected mode and the scanning range

Mode	***Scanning range, m.***								
	14	***16***	***18***	***20***	***22***	***24***	***26***	***28***	***30***
1	48.86	55.84	62.82	69.8	76.78	83.76	90.74	97.72	104.7
2	24.36	27.84	31.32	34.8	38.28	41.76	45.24	48.72	52.2
4	12.18	13.92	15.66	17.4	19.14	20.88	22.62	24.36	26.1
8	6.02	6.88	7.74	8.6	9.46	10.32	11.18	12.04	12.9
16	2.94	3.36	3.78	4.2	4.62	5.04	5.46	5.88	6.3

The creation of a survey justification begins with an analysis of the existing state geodetic networks (SGN) in the area of the studied object. Our analysis showed the presence of 11 SGN points, the coordinates of which were re-determined using GNSS (Global Navigation Satellite System) technologies. GNSS measurements by the receiver in static mode made it possible to re-obtain the coordinates of SGN points in the local coordinate system and perform a comparative analysis for a sample of points with high data reliability. The transformation of coordinates from the world system (WGS84) to the local system and network alignment were performed using the transformation file (transition key) of the Leica Infinity software, which is loaded into the GNSS receiver controller and makes it possible to immediately obtain coordinates in the local system.

GNSS technology was also used to determine the coordinates of solid points in static mode in conjunction with total station survey. The need to use a total station survey to create a planned altitude justification is dictated by the difficulty of satellite signal passing inside the pit, and as a result, the occurrence of measurement errors.

The result of ground-based laser scanning is a spatial model formed by a point cloud, each point of which is characterized by coordinates (X, Y, Z) and color. Subsequent desk processing of the resulting point cloud including the processes of combining scans and filtering them was performed using the Maptek I-Site Studio software.

When creating accurate three-dimensional models of objects, combining scans allows reducing the number of blind spots that are formed due to equipment limitations or geometric features of the object. Each scan is performed from different angles to maximize the coverage of the object's surface, then the results of several scans are combined into a single point cloud. This approach allows getting a detailed and complete model of the object.

The data filtering process is necessary to remove noise and unwanted elements to create an accurate and reliable model, as well as, if necessary, reduce the amount of data while preserving information about the geometry of the object. One of the main point cloud filtering methods based on measuring distances to neighboring points is to remove outliers that are far from the main surface of the object.

Coloring the points of the cloud in real colors allows decrypting the studied section of the pit using a three-dimensional model. The coordinates of the points, determined with an accuracy of 10 mm, make it possible to carry out the necessary measurements of the geometric parameters of cracks, rock boundaries and discontinuities with sufficient accuracy.

The geometric parameters of the structural features of the rock mass were also measured in the Maptek I-Site Studio software. The following geometric parameters of the structural elements are determined: the fall, the direction of the fall, the average distance between the cracks and the coordinate reference of the measurement sites (Figure 2).

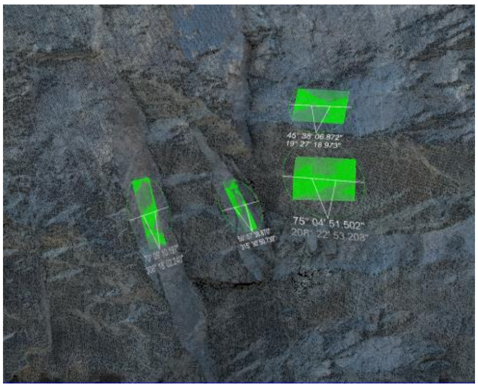

Figure 2 - Measuring process of structural elements geometric parameters

The obtained crack occurrence parameters are exported to Excel spreadsheet, the fragment of which is shown in Table 2.

Table 2 - Results of determining of cracks occurrence elements

No.	***Y, m***	***X, m***	***Z, m***	***Fall, degree***	***Fall direction, degree***
1	33437.581	19307.788	354.510	78.360	354.074
2	33437.631	19307.933	355.042	48.442	151.849
3	33435.970	19308.274	354.721	50.302	15.276
4	33436.087	19308.168	355.399	45.830	166.297
5	33438.774	19307.319	353.699	85.607	212.191
6	33446.847	19306.707	354.949	85.156	30.809
7	33447.120	19306.913	355.350	37.122	184.027
8	33447.620	19306.556	354.919	81.196	179.346
9	33457.285	19305.269	355.323	62.497	30.894
10	33457.465	19305.359	355.935	34.136	185.924
...					

Kinematic analysis based on rock jointing measurements.

The analysis of the condition of separate benches is based on the study of the properties of the rock formations composing them, structural elements and their features, the presence of weak rock contacts, faults, natural rock jointing, the degree of negative impact of drilling and blasting, weathering and oxidation processes. All of these factors, from the point of view of sustainability, have a negative impact to one degree or another. The task is to identify the dominant risk factors that can lead to local bench failure and deformations [[11], [12], [13], [14]].

The benches of the Chiganak deposit are composed of rocky and semi-rocky soil, broken by cracks of various orientations and intensities. Instability in such rock mass occurs by shifting along cracks or by overturning blocks. The possibility of such cases is determined by the spatial orientation of crack systems and man-made outcroppings of slopes. The complex of issues related to the study of the potential for crack stability violations with the fulfilment of the conditions of a special limit equilibrium is called kinematic analysis.

The Rocscience software package provides a special product named Dips for interactive analysis of geological data based on the orientation of crack systems to perform kinematic analysis and risk assessment of planar and wedge-shaped displacements (Figure 3).

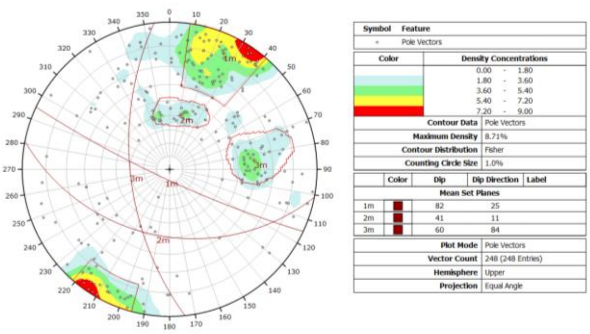

Figure 3 - The crack systems in Dips Rocscience software

The program uses stereographic projection and is a set of tools for various applications and analysis of geological data. The input data affecting the probability of bench failures are the orientation of the slope and crack systems, the slope angle of the bench and the angle of friction along the cracks. As a result of kinematic analysis, the probabilities of rock mass failure modes are determined in Dips [[15], [16], [17]].

There are three types of possible bench failures: Planar Sliding, Wedge Sliding, and Toppling [[16], [17]]:

1. Planar Sliding. A bench failure in the form of a flat slide is possible if the direction of fall of the crack system and the slope surface correspond to the developed space. In this case, the angle of incidence of the crack system is less than the angle of incidence of the slope surface, but exceeds the value of the angle of internal friction along the cracks. If these conditions are met, then the fragments of the bench limited by systems of cracks in the form of blocks have the potential to shift towards the developed space. The data and assessment of the possibility of flat sliding is shown in Figure 4.

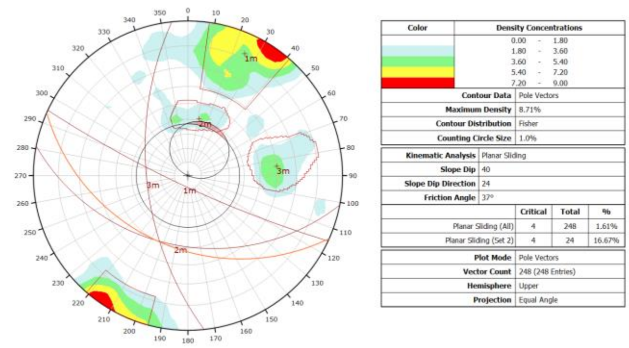

Figure 4 - Planar Sliding analysis

2. Wedge Sliding. This type of bench failure can occur in the open pit walls of pits, when two diagonal systems of cracks falling about the slope form a wedge, which is capable of shifting in the direction of the space left after mining. The condition for the possibility of such a displacement is the slope of the line of intersection of these planes towards the mining space, exceeding the value of the angle of internal friction along the cracks. Under these conditions, the displacement of the rock block in the form of a wedge occurs under the action of gravity. Kinematic analysis of wedge-shaped bench failure is an important tool for assessing the risks of bench failure in pits. It allows making preliminary calculations and identifying areas of increased risk of bench failure, which makes it possible to take appropriate measures to ensure the safety of mining operations. The data and assessment of the possibility of wedge sliding are shown in Figure 5.

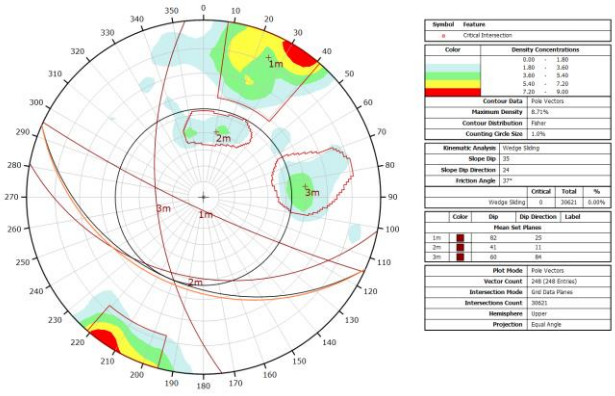

Figure 5 - Wedge Sliding analysis

3. Direct Toppling. This type of bench failure occurs when a rock mass fall along a vertical plane perpendicular to the slope surface. Direct toppling is often registered in pits where the slopes have a steep angle and the rocks have low strength. An important condition contributing to direct toppling is a decrease in the strength of the contour zone as a result of weathering, erosion, the influence of drilling and blasting, seismic activity and other factors. Direct toppling monitoring at a pit is essential to ensure the safety of workers and prevent devastating accidents. The data and assessment of the possibility of direct toppling are shown in Figure 6.

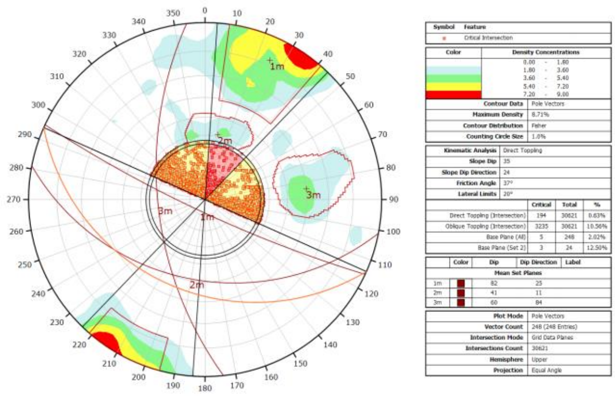

Figure 6 - Toppling analysis

The sensitive analysis of the «slope angle» parameter was realized to assess the actual condition of the benches of the open pit wall of the pit and make design decisions. The results of the analysis showed that a further increase in the slope angles is impossible due to a sharp increase in the risk of bench failure. The probability of direct toppling with the current slope angle parameters of 40 degrees already has a fairly high probability, and with an increase of 5 degrees, it doubles and has an extremely high value [[20], [21], [22], [23], [24]]. The potential risks for all types of bench failures with a further increase in the slope angle and the walls of the pit are shown in Table 3.

Table 3 - Impact of increasing slope angle on the degree of potential risk of failure

Slope angle, degree	***Planar sliding, %***	***Wedge sliding, %***	***Direct toppling, %***
40	16.7	1.28	29.17
45	37.5	5.43	58.33
50	58	9.72	70.83
55	66.67	12.71	75
60	66.67	15.63	75
65	66.67	20.29	75
70	66.67	27.82	75
75	66.67	35	75
80	66.67	41.4	75
85	66.67	50	75

Results and Discussion

Laser scanning of the pit slope section of the Chiganak barite deposit was carried out using a Leica HDS 8800 mining laser. The survey justification for this was created using GNSS technologies. The density of laser scanning throughout the entire area was 10 mm or higher. A representative volume of geospatial data on structural elements of the rock mass was collected in the form of an accurate three-dimensional model. Based on this model, measurements were made of the geometric parameters of structural elements necessary for conducting kinematic analysis: the dip, the direction of dip, the average distance between cracks, and the coordinate reference for measurement sites. A kinematic analysis was then performed using the Dips software package. The results showed the probability of all three types of potential bench failures at a current slope angle of 40 degrees. The highest potential risk of failure is in direct toppling, which amounts to 29.17%. To evaluate the design solutions for increasing the slope angles, a thorough analysis was conducted using the slope angle as a parameter, with an interval of 5 degrees. This analysis revealed that it is not possible to further increase the angle due to the high probability of direct toppling at the current angle of 40 degrees. With an increase of just 5 degrees, the probability of toppling becomes extremely high, doubling from the current value.

Laser scanning is an excellent data acquisition tool for building three-dimensional models of open pits and their elements. The three-dimensional models obtained apply to solving a wide range of tasks, including studying the rock mass structural features, assessing the open pit slopes' stability and analyzing possible failures. Laser scanners are included in the register of measuring instruments of the Republic of Kazakhstan, which makes it possible to obtain measurements with the declared accuracy, guaranteed by device verification certificates. Laser scanning can be used as a method for generalized data obtaining on the condition of the pit wall section and detailed scans of individual sections of its benches. The use of laser scanning technology makes it possible to significantly reduce the stage of desk processing, since a point cloud is generated during the scanning process. The resulting point cloud, in which coordinates and color are assigned to each point, is immediately imported from the scanner's memory into the software for further processing. The resulting three-dimensional models apply to solving a wide range of tasks. The proposed technology for collecting geospatial data provides the construction of a digital three-dimensional model with a pixel size of 10 mm. The limitation of using this model is based solely on its pixel size.

Conclusions

The proposed technique for geospatial data collecting based on laser scanning and GNSS technologies can be used to obtain three-dimensional models that provide the required accuracy. Laser scanning has no restrictions and is applicable in pits for the extraction of any type of minerals. The speed of three-dimensional model obtaining and its accuracy make it possible to quickly solve topical issues arising during mining operations. It is planned to further develop data collection technology based on laser scanning to construct a more detailed digital three-dimensional model of open pit elements to study microcracks and their impact on the rock mass condition.

Conflicts of interest. No conflicts of interest

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Лазерлік сканерлеу негізінде тау массивінің құрылымдық ерекшеліктерін зерттеу

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ТҮЙІНДЕМЕ

Тау-кен жұмыстарының қауіпсіздігі мәселесінде карьердің беткейлерінің тұрақтылығын бақылау маңызды рөл атқарады. Көлбеу тұрақтылықты бағалау және тәуекелдерді басқару карьерлерді қауіпсіз және тиімді пайдалануды қамтамасыз ету үшін міндетті болып табылады. Лазерлік сканерлеу технологиясы техногендік объектілердің модельдерін құру үшін геокеңістіктік деректерді жинаудың негізгі әдістерінің бірі. Тау-кен өндірісінде лазерлік сканерлеу түсірілім жұмыстарында, өлшеулерде, бақылауларда және тау жыныстарының беткейлерінің құрылымдық ерекшеліктерін зерттеуде кеңінен қолданылады. Мақалада қарастырылған технологиялық тізбек: геокеңістіктік деректерді жинау, алынған деректерді өңдеу арқылы жер бедерінің моделін құру және практикалық мәселелерді шешу үшін алынған модельді одан әрі пайдалану. Лазерлік сканерлеудің оңтайлы параметрлерін таңдау карьердің технологиялық ерекшеліктеріне, пайдаланылатын жабдықтың техникалық сипаттамаларына, қойылған міндеттерді шешу үшін қажетті сканерлеу тығыздығына негізделуі керек. Мақалада зерттеу объектісіндегі ықтимал опырылуларға кинематикалық талдау жүргізу мақсатында массивтің құрылымдық ерекшеліктерінің қажетті геометриялық параметрлерін анықтау үшін алынған модельді қолдану көрсетілген. Кинематикалық талдаудың алынған нәтижелері негізінде тау-кен жұмыстарын одан әрі жүргізу және ықтимал опырылу қаупін азайту бойынша ұсыныстар жасалды. Ұсынылған технология кең ауқымды мәселелерді шешу және ашық әдіспен өндірудің қауіпсіздігін қамтамасыз ету үшін әр түрлі пайдалы қазбалар кен орындарында кейіннен жер бедері үлгісін салу арқылы лазерлік сканерлеу үшін пайдаланылуы және бейімделуі мүмкін. Лазерлік сканерлерді Қазақстанның өлшеу аспаптарының тізіліміне енгізудің арқасында өлшеу дәлдігінің жоғары сенімділігі қамтамасыз етіледі. Технология карьер жақтары бойынша жалпылама деректерді алуға және жеке ойықтарды егжей-тегжейлі сканерлеуге мүмкіндік береді. Маңызды артықшылығы - сканерлеу кезінде нүктелердің бұлты автоматты түрде жасалады, бұл камералық өңдеуді азайтады.

Түйін сөздер: лазерлік сканерлеу, геокеңістіктік деректер, рельефтің сандық моделі, кинематикалық талдау, карьер, тау массивінің құрылымы.

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Исследование структурных особенностей горного массива на основе лазерного сканирования

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АННОТАЦИЯ

Мониторинг устойчивости откосов уступов и бортов карьера играет важную роль в вопросе безопасности ведения горных работ. Оценка устойчивости откосов и управление рисками являются обязательными для обеспечения безопасной и эффективной эксплуатации карьеров. Технология лазерного сканирования является одним из основных методов сбора геопространственных данных для построения моделей техногенных объектов. Лазерное сканирование широко применяется в горном деле при выполнении маркшейдерских работ, измерений, мониторинга и изучения структурных особенностей на выходах горного массива. В статье рассмотрена технологическая цепочка: сбор геопространственных данных, обработка полученных данных с построением модели местности, и дальнейшее использование полученной модели для решения практических задач. Выбор оптимальных параметров лазерного сканирования должен основываться на технологических особенностях карьера, технических характеристиках используемого оборудования, на требуемой плотности сканирования, необходимой для решения поставленных задач. В статье показано использование полученной модели для определения необходимых геометрических параметров структурных особенностей массива с целью проведения кинематического анализа потенциальных обрушений на объекте исследования. На основе полученных результатов кинематического анализа были выработаны рекомендации по дальнейшему ведению горных работ и снижению рисков потенциальных обрушений. Предложенная технология может быть использована и адаптирована для проведения лазерного сканирования с последующим построением модели местности на различных месторождениях полезных ископаемых для решения широкого круга задач и обеспечения безопасности открытых горных работ. Благодаря включению лазерных сканеров в реестр измерительных приборов Казахстана, обеспечивается высокая достоверность точности измерений. Технология позволяет как получать обобщенные данные о бортах карьера, так и детализированные сканы отдельных уступов. Существенным преимуществом является автоматическая генерация облака точек во время сканирования, что сокращает камеральную обработку.

	Ключевые слова: лазерное сканирование, геопространственные данные, цифровая модель местности, кинематический анализ, карьер, структура горного массива.

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