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Modern data analysis technologies used for geomechanical monitoring. Review

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ABSTRACT
The paper considers the possibilities of modern technologies and software that make it possible to create continuity of geomechanical monitoring of man-made objects from shooting in automatic mode, robotic surveillance systems, transmitting information over the Internet to cloud storage, to performing stability calculations, determining the parameters of displacement and deformation of slopes of ledges and sides of quarries. The development of modern technologies for collecting and processing information allows the use of artificial neural networks that are adapted for modeling geodetic deformations. Technogenic objects, which are very complex systems, have a huge number of external factors affecting the stability of the mountain range, so it becomes incredibly difficult to take into account and determine the amount of displacement and deformation. Due to the complexity and variety of influencing factors, it becomes necessary to use a new system for assessing the state of objects, called "neural networks". The training of such a system is based on the already available research results collected during the direct operation of industrial enterprises. Neural networks can become an alternative to various methods of describing deformation processes, especially in the continuous monitoring of man-made objects, where there is no a priori knowledge of the underlying deformation processes. For effective monitoring and forecasting of deformation processes at a mining enterprise, a multiparametric monitoring method is needed, which includes a comprehensive system based on GPS measurements, supplemented with data from sensors for changes in water level and changes in stresses and deformations of the array. The results of automated survey and data recording sent to the cloud storage are distributed using "Big Data" technology and analyzed by geoinformation systems. In turn, the adaptation of neural networks to model deformations allows specialists to obtain a good alternative to the description of structural deformations of the mountain range.

Keywords: The concept of the "Internet of Things", deformation monitoring, "Big Data", neural networks, analytical models, modeling of deformation processes.

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Introduction

Application of the concept of the "Internet of things" in the organization of observations of the object.

The automation of geodetic observations began in the 1980s, when personal computers and analog signal modems appeared, which were used by engineers to control electronic sensors and record sensor data on magnetic drives. At this time, time measurements were increasingly replaced by constant and continuous observations in time. The prerequisite for automatic measuring digital systems in geodesy was the availability of suitable software for touch control and data processing [1]. These strain monitoring systems have been developed as isolated applications for individual personal or industrial computers with limited or no network functions.

Even today, more modern systems lack such functions as an open network and data interfaces for machine-to-machine interaction with third-party software, which makes it difficult to integrate them into sensor networks [2]. To coordinate measurements over large areas, monitoring systems must be integrated into sensor networks.

The possibilities of the "Internet of Things" concept and modern technologies make it possible to simplify access to the network in engineering geodesy and surveying without costs and technical problems [3].

The emergence of small single-board computers, such as the Raspberry Pi, made it possible in a short time to create inexpensive middleware for monitoring and controlling tasks using rapid prototyping methods. These embedded boards are full-featured computers with an ARM or MIPS processor, memory, and I/O interfaces. In addition, any application, for example, the monitoring software discussed, can be launched (Fig. 1). The concept of embedded sensor nodes is also applicable to portable Android devices such as smartphones and tablet computers. They can provide the necessary interfaces for connecting sensors, as well as mobile Internet access via 3G/4G. The reuse of such universal devices can reduce the effort and cost of implementing sensor networks [3].

At the moment, foreign research groups and universities are already working on the development of this direction. The result of such work is a German system called OpenADMS [4]

It consists of several components:

- Open ADMS Control is a software for personal computers designed to receive short–term data from sensors.

- Open ADMS Web is a system designed to work with a server, its main task is to work with a complex of sensors and devices in the long term.

This system allows real-time observations of the reference points of the observation stations of the geomonitoring system and reflects on the graph the displacement and changes in the coordinates of the observation point, shown in Fig. 2.

The advantage of using this system can be called the continuity of the work of the surveying department. While specialists are in the field, reproducing the shooting or it is performed automatically by robotic surveillance systems, the data obtained is immediately sent via the Internet (or an internal LAN) to cloud storage. The data from the repository is used to perform further calculations of stability, the volume of work performed, etc.

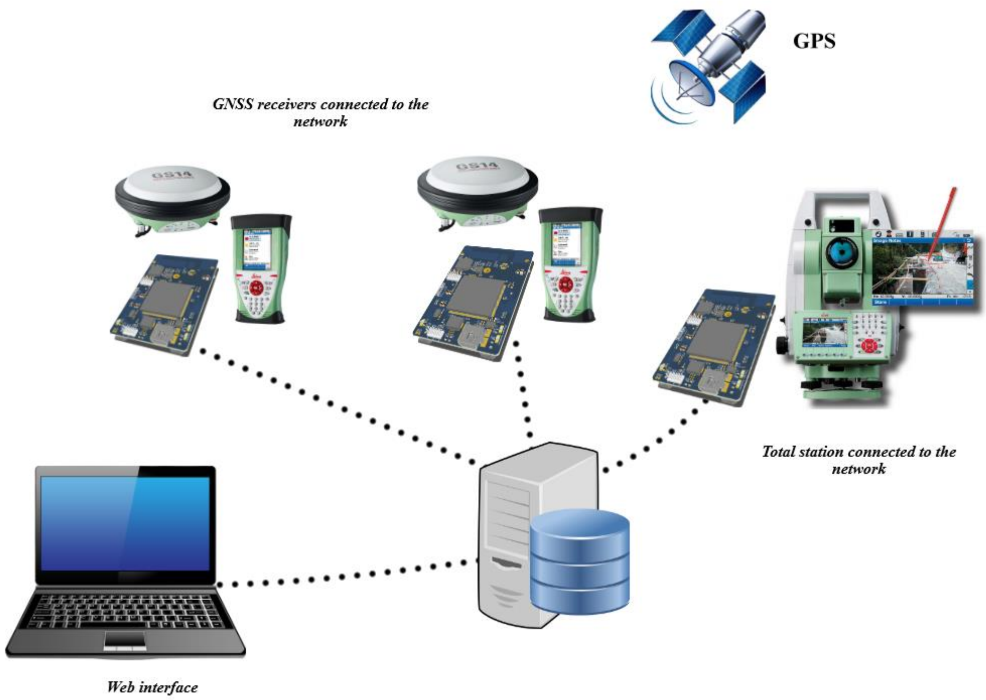

Figure 1 - The scheme of the "Internet of Things"

Figure 2 - Observation of the displacement of the point coordinate using OpenADMS

Big Data and prospects of application in desk work

The term "big data" (BD) was "officially" introduced by the Oxford English Dictionary in 2013. He associates the term BD with a large data set that is (almost) impossible to manage — process using "traditional" tools [5].

BD can carry "big errors", such as lack of consistency and reliability, "false" data, noise, lack of representativeness, incomplete information, etc.

Currently, most of the "big data" consist of spatial data, i.e. discrete representations of continuous phenomena. Spatial data is represented by the following basic models:

a) raster (grid): satellite images are good examples of raster data;

b) vector: consists of points, lines, polygons, and their combined (or multi-) analogs;

c) network: graphs consisting of spatial networks form another important data type used to represent road networks.

The problem of working with big data arises when shooting large objects with a high level of detail. The total amount of information about the object can reach huge volumes, and every year it will only grow exponentially. The main task of Big Data is to work with such a volume of data, their analysis, and processing. Within the framework of this concept, cloud storage, database software, machine learning, etc. are widely used.

Application of neural networks

The latest interesting developments in the direction of software development are the method of machine learning and the use of neural network technology. Technogenic objects are very complex systems that have a huge number of external factors, which makes it incredibly difficult to take them into account, so mathematical models have a discrepancy with the established forecasts of their condition [[6], [7]].

Due to the complexity of the influencing factors, when trying to take into account most of the conditions, a model is obtained that is difficult to fully describe with dependencies. For this reason, it becomes necessary to use new methods for assessing the state of objects, using a system called "neural networks" for this purpose. Though they are in fact artificial neural networks, they are often called neural networks or nets which are basically IT systems that mimic biological neural networks [8].

The training of such a system is based on the already available research results collected during the direct operation of industrial enterprises. Artificial neural networks are adapted for use in modeling geodetic deformations (Fig.3).

Surveyors and surveyors have long been faced with the problem of finding effective solutions to approximation functions that determine the

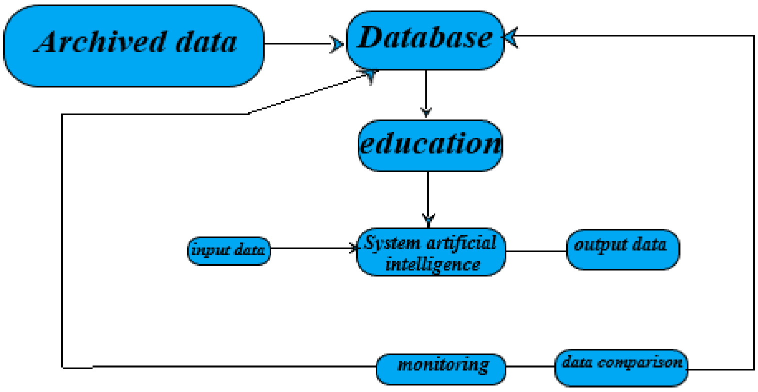

Figure 3 - Neural network operation diagram

amount of displacement and deformation, especially when working with continuously controlled processes. Most solutions are obtained in the time domain, since measurements are currently obtained online in the form of continuous or discrete time sequences.

This system has a number of features:

- The system constantly accumulates data and improves itself, which over time will improve the quality of creating an object model, and will allow analysis under changing operating conditions.

- It will be impossible to make clear dependencies within this system, since it is closed, and does not allow the user to see on the basis of which calculations such a calculation was obtained, however, the user can still make a comparison based on the data entered and the result obtained.

- The real physical model may not fully correspond to the one that was built by the neural network.

The adaptation of neural networks to model deformations allows specialists to obtain a good alternative to the description of structural deformations. Certain parameters, in this case, weights, inherently describe the mapping between input and output data, but cannot be used in any other way as a representation of a typical mathematical function for the deformation process. It is very important to note that the results of using neural networks strongly depend on the choice of both input and output data, as well as the architecture of the network used, since they are able to learn anything. Figure 4 shows graphs of real measurements and models built by a neural network trained by researchers from the Institute of Geodesy and Photogrammetry of the Braunschweig Technical University. In the left part of the graph, the parameters are adjusted, after which the neural network makes its own forecast regarding further changes in the coordinates of the geodetic point. On the graph, in the right part of it, you can track a large degree of convergence of real measurements and the model of changing the coordinates of a point built by a neural network.

Neural networks also have a disadvantage, which is that there is no single analogous solution for any given set of input-output data, since the parameters determined depend on various settings performed during the learning process, which rely solely on personal human judgment. However, neural networks can become an alternative to methods of describing deformation processes, especially in the continuous monitoring of man-made objects, where there is no a priori knowledge about the underlying deformation processes. Thus, they can serve as an addition to the existing methodology for modeling deformation processes.

Organization of a comprehensive monitoring system using the latest technologies

The issues of creating an automated geomechanical monitoring system are considered in order to study the state of stability of the Western and Eastern quarries of LLP "JV "Alaigyr" based on the use of GPS equipment and software.

The Alaigyr deposit is located in the eastern part of the Uspenskaya crumple zone. Devonian and carboniferous deposits, and subvolcanic and dike formations take part in the geological structure of the deposit [10]. Of the magmatic formations within the deposit, the subvolcanic body of ore-containing high-potassium liparite porphyries is of the greatest interest. A total of 20 dyke bodies have been identified at the deposit. The Alaigyr lead deposit is localized within the subvolcanic body of liparite porphyries. Since the ore mineralization along the strike has

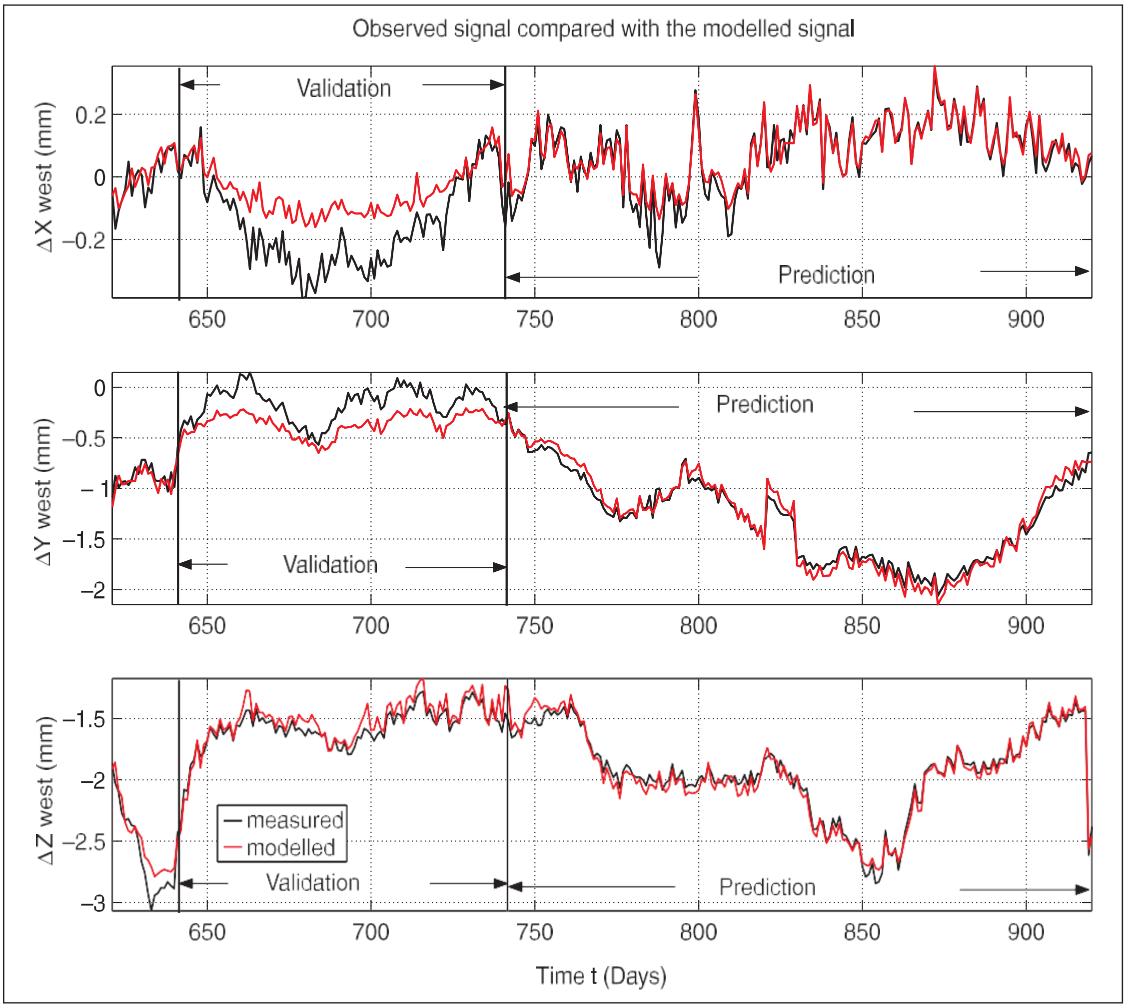

Figure 4 - Graph of comparison of neural network data with real measurements

Table 1 – Summary of the recommended parameters of the ledges of the Eastern quarry

Cut	Type of breed	Slope angle of the ledge, degree	Ledge height, m
I-I	Clay	40	12
	Weathering Crust	50	12
	Carbonaceous-siliceous shales	65	24
	Terrigenous siltstones	65	24
II-II	Clay	40	12
	Rhyolite porphyries	65	30
III-III	Weathering Crust	50	12
	Rhyolite porphyries	65	30
	Beresitized porphyry	65	30
	Tufopeschaniki	50	12
IV-IV	Weathering Crust	50	12
	Rhyolite porphyries	65	30
	Beresitized porphyry	65	30

interruptions, the deposit is conditionally divided into three sections: Western, Middle, and Eastern.

During the exploration of the deposit, 11 major tectonic disturbances were revealed [10]. The most ancient discontinuous disorders complicating the folded structure are consonant longitudinal (sublatitudinal) violations such as thrusts or interplastic disruptions. Violations of this type are characteristic of the entire Assumption crumple zone. A linear type weathering crust has been developed at the deposit, confined to crushing zones of the type of inter-plastic breakdowns between liparite porphyries and host rocks. Weathering crust rocks are represented by intensely fractured rocks, often decomposed to the state of structural and structureless clays.

The stability of the sides and ledges of the Alaigyr deposit is influenced by a huge number of factors, such as the presence of tectonic disturbances, a developed zone of weathering crust, intense fracturing of rocks, waterlogging of the deposit, physical and mechanical properties of rocks, technological features of mining, etc.

In 2018, Mining Research Group LLP carried out work on the geomechanical justification of the parameters of the quarries of the mining complex at the Alaigyr deposit. Analysis of the simulation results shows that the least stable areas are the upper ledges composed of clays (SRF = 0.63), which indicates the instability of the sides and ledges of the Eastern Quarry. The simulation results are summarized in Table 1.

Based on the Alaigyr field development project, a combined scheme for monitoring the stability of the sides of the quarry and ledges was chosen.

To monitor the stability of the sides, a GPS base station will be used, which is installed on the roof of the production and administrative building. Four observation profiles and eight scoring reference points are fixed on the sides of the quarries to install a GPS receiver. (Figure 5, 6)

Also, based on the geomechanical justification of the quarry parameters, the location of the robotic electronic total station is selected.

Geomechanical control at the quarries is carried out in order to obtain reliable information about the condition of the sides of the quarry at various stages of field development. One of the ways to ensure such control is to conduct instrumental observations, on the reliability of the implementation of which the adequacy and timeliness of decision-making on emerging deformations of the instrument array depends. Untimely response to emerging deformations can lead to the death or loss of the working capacity of people and increase production costs.

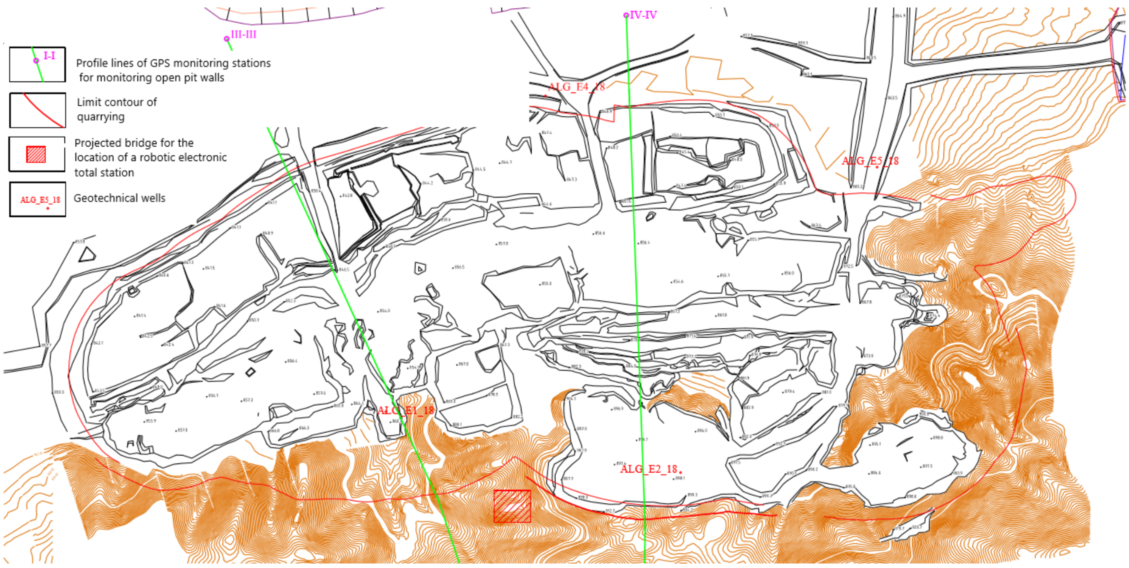

Figure 5 - Layout of profile lines for monitoring the stability of the eastern side of the quarry

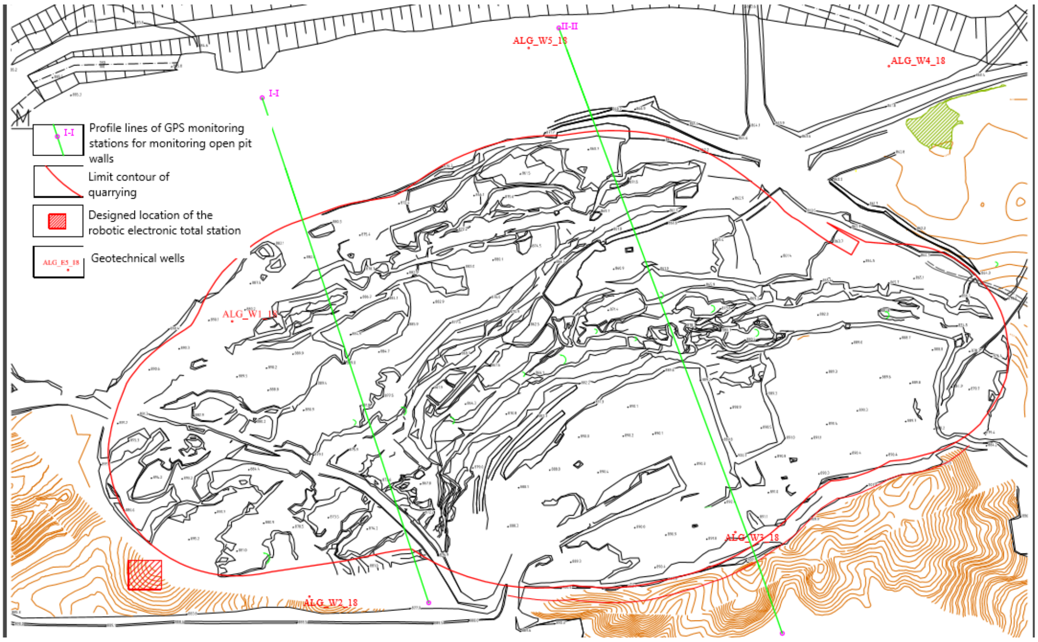

Figure 6 - Layout of profile lines for monitoring the stability of the western side of the quarry

Currently, there is a large amount of data, both in the field of hardware layout of observational surveying networks, and software products that provide analysis and processing of incoming information from deformation sensors. One of the main manufacturers whose GPS equipment is used in the creation of information collection and processing systems (GPS receivers and communication equipment) are Leica Geosystems, Trimble, Garmin, etc [9].

In the field of software that allows you to fully automate the control mode of deformation sensors, collect and archive statistical data, process data in real-time, as well as notify about exceeding permissible values of deformations, the following companies have achieved the greatest success: InteTrak (Orion Monitoring Systems, Inc); 3D Tracker (Condor Earth Technologies); GPS RTK software (Geodetic Research Laboratory (GRL) at UNB) [11].

Using high-precision equipment operating around the clock in real-time with an advanced warning system helps to secure mining operations (for example, to remove equipment and field workers from the zone of probable collapse). In view of the fact that the mountain range is usually heterogeneous, the function of the development of the deformation rate is often not linear in nature. In this regard, high-precision instrumental observations with short intervals between measurements are necessary to determine the transition point of ordinary displacements to the critical zone [1].

This multiparametric remote monitoring system can monitor various characteristics of an unstable landslide on a large scale before it collapses in various aspects, which gives the geomechanical service of the enterprise valuable time to prepare anti-landslide measures [12]. According to the different slope characteristics, different parameters can be combined and different types of sensors can be selected. Then the data is transmitted to the control room using wireless communication technology. In the control room, correct conclusions are given through the system's data analysis system and the expert's experience analysis, which can play a real role in predicting and predicting deformation processes.

To reproduce the real effect of monitoring and forecasting on an unstable slope, a multiparametric monitoring method is needed [[13], [14]]. Based on the ideas presented, a combination of several monitoring methods is proposed [15]. A comprehensive monitoring system based on GPS monitoring is being created, which is complemented by touch monitoring [16].

Firstly, the stability of the slope of the ledge is influenced by many factors. To collect information affecting the stability of the slope, a multiparametric and multi-device monitoring system based on the Internet of Things is proposed.

Secondly, the monitoring cycle of the slope monitoring project is long, so it requires little real-

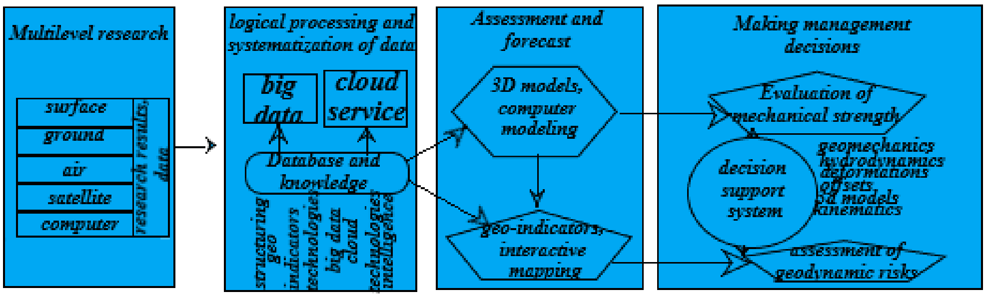

Figure 7 - Geomechanical monitoring system

time data. However, due to the specifics of the monitoring environment, it has high requirements for energy conservation, scalability, and reliability of the wireless transmission network [[6], [7]].

Thirdly, the efficiency and accuracy of monitoring data play an important role in predicting the stability of the slope of the ledge and the side of the quarry [17]. Therefore, the data must be properly processed and classified. The key to the data management process is to extract useful data from the array of monitoring data that are useful for the forecasting process [18]. Monitoring data is transmitted to the remote monitoring information management center using ZigBee technology. A large-scale information management system for slope monitoring is being created (Fig.7). They manage a database of ground and deep displacements, a database of attributes of water level changes, and a database of attributes of stress and strain changes. Through Internet technologies, geomechanics can view data in each database. To make it easier for users to manage the application, connection, device, and other contents of the intermediate service components of the Internet of Things, an Internet-based web services system is used [[19], [20], [21], [22]].

Wireless sensor network data transmission and middleware management are implemented respectively. The Access database stores information about hardware, information about applications, and so on. The Wireless Sensor Network Data Interface (API) packages wireless sensor data into an interface and provides a call to the user. It is economically feasible to use such a system at large facilities where there is a large amount of data and work performed. Due to the automation of the process with the help of robotic devices and sensors, data acquisition is possible in automatic mode [[23], [24]]. The results of the survey and data recording sent to the cloud storage will be distributed using the "Big Data" technology, after which further work with them is possible using geoinformation systems. Potentially, neural network technology can be included in this complex, but training the system will take time and require large computing power [25].

Currently, a database is being created in order to obtain reliable information about the condition of the sides of the quarry at various stages of field development, taking into account the complex mining and geological conditions of development and the results of instrumental observations of the developed integrated monitoring system based on GPS monitoring, which is supplemented by sensor monitoring.

A similar approach can be applied to large facilities such as the Ekibastuz basin coal pits, the Vasilskovskoye gold deposit, the deep pits of the Sokolovo-Sarbay Mining and Production Association, and other enterprises of the mining industry of the Republic of Kazakhstan [26]. In the end we should not forget that beyond the advantages big data has it is also like "(...) the new plutonium. In its natural state it leaks, contaminates, harms. Safely contained & harnessed it can power a city" [27].

Conclusions

Modern technologies and capabilities of the "Internet of Things" concept make it possible to simplify access to the network in engineering geodesy and surveying without costs and technical problems. The German OpenADMS system, based on working with a complex of sensors and devices, allows real-time observations of the reference points of the observation stations of the geomonitoring system and reflects on the graph the displacements and changes in the coordinates of the observation point.

The total amount of information about the object can reach huge volumes, and every year it will only grow exponentially. When shooting large objects with a high level of detail, the main task of Big Data is to work with such a volume of data, their analysis, and processing.

Monitoring of man-made objects includes taking into account the complexity of influencing factors, while most of the conditions are difficult to fully describe with dependencies. For this reason, it becomes necessary to use new methods for assessing the state of objects, using a system called "neural networks" for this purpose. The adaptation of neural networks to model deformations allows specialists to obtain a good alternative to the description of structural deformations.

Neural networks can become an alternative to methods of describing deformation processes, especially in the continuous monitoring of man-made objects, where there is no a priori knowledge about the underlying deformation processes. Thus, they can serve as an addition to the existing methodology for modeling deformation processes

The technology of the "Internet of Things" and "Big Data" can really improve the situation, simplify the way of data collection, bringing desk work to almost automatic execution, but the use of these technologies does not yet have a sufficient practical basis.

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Геомеханикалық мониторингті орындау үшін қолданылатын қазіргі заманғы деректерді талдау технологиялары. Шолу

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ТҮЙІНДЕМЕ
Жұмыста автоматты режимде түсіруден, роботтандырылған бақылау жүйелерімен техногендік объектілердің геомеханикалық мониторингінің үздіксіздігін құруға, интернет желісі бойынша ақпаратты бұлтты қоймаға беруге, орнықтылық есептеулерін орындауға, карьерлердің кемерлері мен ернеулері еңістерінің жылжу және деформация параметрлерін анықтауға мүмкіндік беретін қазіргі заманғы технологиялар мен бағдарламалық қамтамасыз етудің мүмкіндіктері қарастырылды. Ақпаратты жинау мен өңдеудің заманауи технологияларын дамыту геодезиялық деформацияларды модельдеуге бейімделген жасанды нейрондық желілерді пайдалануға мүмкіндік береді. Өте күрделі жүйелер болып табылатын техногендік объектілерде массивтің тұрақтылық жағдайына әсер ететін көптеген сыртқы факторлар бар, сондықтан қозғалыс пен деформацияның мөлшерін ескеру және анықтау өте қиын. Әсер етушілердің күрделілігі мен алуан түрлілігіне байланысты "нейрондық желілер" деп аталатын объектілердің жағдайын бағалаудың жаңа жүйесін қолдану қажет. Мұндай жүйені оқыту өнеркәсіптік кәсіпорындарды тікелей пайдалану кезінде жиналған қолда бар зерттеу нәтижелеріне негізделген. Нейрондық желілер деформациялық процестерді сипаттаудың әртүрлі әдістеріне балама бола алады, әсіресе олардың негізінде жатқан деформациялық процестер туралы априорлық білімі жоқ техногендік объектілерді үздіксіз бақылау кезінде. Тау-кен кәсіпорнында деформациялық процестерді тиімді бақылау және болжау үшін GPS-өлшеулер негізінде кешенді жүйені қамтитын мониторингтің көп параметрлі әдісі қажет, ол су деңгейінің өзгеру датчиктерінің деректерімен және массивтің кернеулері мен деформацияларының өзгеруімен толықтырылады. Бұлтты қоймаға жіберілген автоматтандырылған түсірілім және деректерді жазу нәтижелері "Big Data" технологиясының көмегімен таратылады және геоақпараттық жүйелермен талданады. Өз кезегінде нейрондық желілерді модельдердің деформацияларына бейімдеу мамандарға массивтің құрылымдық деформацияларын сипаттауға жақсы балама алуға мүмкіндік береді.

Түйін сөздер: «Заттардың интернеті» түсінігі, деформация мониторингі, «Үлкен деректер», нейрондық желілер, аналитикалық модельдер, деформация процестерін модельдеу.

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Современные технологии анализа данных применимые для выполнения геомеханического мониторинга. Обзор

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Аннотация
В работе рассмотрены возможности современных технологий и программного обеспечения, позволяющие создать неразрывность геомеханического мониторинга техногенных объектов от съемки в автоматическом режиме, роботизированными системами наблюдения, передачи информации по сети интернет в облачное хранилище, до выполнения расчетов устойчивости, определения параметров сдвижения и деформаций откосов уступов и бортов карьеров. Развитие современных технологий сбора и обработки информации позволяет использовать искусственные нейронные сети, которые адаптированы для моделирования геодезических деформаций. Техногенные объекты, представляющие собой очень сложные системы, обладают огромным количество внешних факторов, влияющих на состояние устойчивости горного массива, поэтому учесть и определить величину сдвижения и деформации становиться невероятно сложно. Из-за комплексности и разнообразия влияющих факторов, возникает необходимость использовать новую систему оценки состояния объектов, называемую «нейронными сетями». Обучение подобной системы, основывается на уже имеющихся результатах исследований, собранных при непосредственной эксплуатации промышленных предприятий. Нейронные сети могут стать альтернативой разнообразным методам описания деформационных процессов, особенно при непрерывном мониторинге техногенных объектов, где нет априорных знаний о лежащих в их основе деформационных процессах. Для эффективного мониторинга и прогнозирования деформационных процессов на горном предприятии необходим многопараметрический метод мониторинга, который включает в себя комплексную систему на основе GPS-измерений, дополняется данными датчиков изменения уровня воды и изменений напряжений и деформаций массива. Результаты автоматизированной съемки и записи данных, отправленные в облачное хранилище, распределяются с помощью технологии «Big Data», и анализируются геоинформационными системами. В свою очередь адаптация нейронных сетей к деформациям моделей позволяет специалистам получить хорошую альтернативу описанию структурных деформаций горного массива.

Ключевые слова. Концепция «Интернета вещей», мониторинг деформации, «Большие данные», нейронные сети, аналитические модели, моделирование деформационных процессов.

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