Geotechnological aspects of mining processes automation

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Abstract. The article is devoted to the geotechnologies’ implementation for the mineral resources integrated development on the basis of modern software and hardware systems integrated into the mining enterprise general management system. In particular, the authors discuss a scientific idea, which consists in exploring the possibility of forming technical and technological requirements for the design of robotic systems to ensure the effective and safe release of coal under-roof stratum on the face conveyor based on the use of automation and robotics elements.

1. Introduction

In connection with the exhaustion of readily available mineral reserves, deposits of rich coal seams, as well as alluvial diamondiferous deposits, characterized by difficult mining and geological conditions, are involved in the development: depth increases, bedding prevails in thick seams. New conditions require appropriate advanced science-intensive technical and technological solutions that ensure safe and efficient production [1, 2]. Importance of implementation and the readiness of the transition of the mining industry to digital – automated and robotic “unmanned” technologies is noted at all levels in Russia and abroad, which is reflected in the policies of the international technical committee ISO / TC 82 “Mining” and the subcommittee ISO / TC82 / SC 8 “Advanced automated mining systems”.

The need to develop components of “unmanned mines” is confirmed in the long-term program for the development of the Russian coal industry until 2030, approved by the Government of the Russian Federation Decree of June 21, 2014 No. 1099-r, where the main direction of technological development in relation to underground mining provides for the development and implementation of “unmanned” mineral mining systems based on integrated mechanization and automation [3]. Therefore, the most important direction of sustainable development of the coal industry is the implementation of geotechnologies for the integrated mineral resources’ development on the basis of modern software and hardware systems integrated into the general management system of the mining enterprise.

2. Robotics design

Work on the design of robotics used in underground production began in the second half of the 70’s of the 20th century with the development of destruction machines controlled remotely by Brokk [4, 5]. In the future, a number of different projects and prototypes of remotely controlled systems designed to help with tunneling operations appeared, a special place should be given to the self-propelled robot,
the anchor installer, which appeared in the USA, developed by the Berkeley Institute [6]. Drilling and installation of anchors was the main direction of underground robotics in the late 70’s and the first half of the 80’s of the 20th century.

At the same time, research and development work began on the development of robotic systems for underground work in the USSR, the peak of which occurred in the second half of the 80’s. One of the most unique was the project of a robotic complex of equipment for drilling and blasting operations, developed in the Donetsk branch of Giprougolavtomatizatsia, capable of performing up to 210 various operations [7]. In the future, work on the application and development of robots for working underground until the mid-2010’s was mainly carried out in two directions – robots for conducting inspections of emergency facilities and semi-autonomous remote-controlled self-propelled loaders and trucks for underground mining of ore; in the second direction the Atlas Copco company development in this area should be highlighted, with its underground transport control system and semi-autonomous scooptram automation moving systems, now it is Epiroc company [8].

Work in the first direction with varying success is being carried out in all developed countries up to the present day; self-orientation systems of mobile robotic systems in underground workings are of the greatest interest. In this area, scientists from the USA take absolute leadership, developments are carried out by both large companies and institutes, it is worth noting the work carried out at the University of Alaska Fairbanks, where a team of scientists with the participation of Dr. Richard Weiss and Rajiv Ganguli developed and tested in practice self-orientation methods for flying and self-propelled drones in the mines [9]. Despite this, knowing the modern extracting equipment for mining, we see that complex robotic systems have not yet been widely adopted. Robots are used only in dozens of mines and are mainly associated with heading, fastening the face, transportation, and at enterprises that are not hazardous in gas and dust.

Since the mid-2010s, the German company Marco Systemanalyse und Entwicklung GmbH has been actively engaged in technological and engineering work on the introduction of elements, technologies, and methods of extraction work. So in the Kemerovo region by 2017, an experimental longwall was launched at the Polysaevskaya mine with the introduction of a robotic system for evaluating the longwall straightness, acoustic control of collisions on the roof, and monitoring the position of sections and their elements based on computer vision systems [10]. There are many companies on the world market that are developing modern systems for the automated control of mining equipment elements for a wide range of purposes. Companies developing and supplying integrated solutions for automated equipment management are an order of magnitude smaller.

The most advanced and famous are: Elgor + Hansen S.A. (Chorzow, Poland), FAMUR Group (Poland), MARCO Systemanalyse und Entwicklung GmbH (Germany), EEP Elektro-Elektronik Pranjic GmbH (Germany), Caterpillar (USA), TIEFENBACH Control Systems GmbH (Germany), Komatsu (Japan). Two companies – Caterpillar and Tiandi – present on their websites longwall complexes and related equipment for mining thick seams with free flow outlet of coal. However, the outlet technologies are similar to each other and coal outlet is carried out on a goaf conveyor belt, and not on a face conveyor [11]. This method of extraction has serious enough disadvantages that affect the complexity and cost of its use:

- a significant increase in the size of the support;
- the presence of an additional goaf conveyor;
- complication of the roof support structure;
- the need for the introduction of an additional reloading device into the complex;
- at the junction of the longwall with the conveyor gallery [12].

At the same time, the system of intelligent control of the outlet means (the protection shield on the goaf side, the goaf conveyor) is not considered as a separate subsystem, but is implemented through free (standby) channels on the basis of the produced automated electro-hydraulic control systems.

That is, a system for automated control of the outlet process is implemented on the basis of integrated longwall control systems; hydraulic control of technical means providing outlet (hydraulic
jacks for opening windows and moving the conveyor) is carried out through additional (free) of electro-hydraulic control channels.

A promising platform for creating a new generation of robotic complexes for efficient and safe underground mining with the outlet of minerals from the overlying stratum and explosion-free methods of softening the massif is the fencing-supporting mechanized support with controlled outlet on the face conveyor developed by the FRC CCC SB RAS [13].

Technological features of the outlet process to the face conveyor, as well as the support sections’ construction, does not allow the operator to effectively monitor the outlet process, which requires a transition from standard elements of the longwall complex automated control to robotic control systems with technical vision elements. The outlet process is included in the control system additionally, for this reason, the outlet technical means robotic control principles’ development, even at the initial level, it is worth considering as the development of a control subsystem, which in the future is integrated into the applied system of complex intellectual and electrohydraulic control of the longwall complex.

When developing elements for the robotization of coal outlet to the face conveyor, one should focus on the possibility of integrating robotic outlet systems into a typical control system for sections of a longwall complex, which requires the use of standard hydraulic control elements and sensors from the main manufacturers of integrated mining automation systems. With this article authors’ participation, technology simulation model for the effective development of coal deposits by a robotic complex with a controlled outlet of the under-roof stratum was developed at the FRC CCC SB RAS. The technology is evaluated and its rational parameters are determined, in which the use will be most effective. Using the developed tools, various modes of the under-roof stratum outlet were studied: individual, wave, group, and areal [14].

It was revealed that the optimal parameters cannot be maintained without the organization of complex systems for controlling the flow of rock from each section feeders, based on vision systems, which are the basis of the robotic support section with the under-roof stratum controlled outlet. To date, a prototype support section with controlled coal outlet to the face conveyor has been developed and is planned for production, based on RF patent No. 2513952 [15]. Mechanics and kinematics, simulation models are created, objects and methods for organizing the automated rock mass outlet from the under-roof stratum are described, without the outlet parameters and rock approach monitor systems’ control possibility [16], however, the outlet process is not described in detail from the automation and robotization object point of view. The development technologies under different bedding conditions and types have some differences, however, the main tasks of automation and robotization are similar for all of them. For this reason, approaches to the design of control systems are largely similar.

The main tasks of automation and robotization in the framework of the rock mass production technological process include:

- composition determination (“rock-coal” boundary);
- conveyor loading assessment;
- an of the of each section output volumes estimation in real time;
- outlet initiation when the roof hangs, the of dome formation, blockage. The solution of the above problems has a number of serious limitations that do not allow the use of conventional methods used in other industries.

So, to evaluate the composition of incoming rock mass by standard methods is possible only when it is already on the main conveyor, and taking into account the output performance of each section on average about 50 kg/s and the presence of simultaneous outlet of, for example, 50 sections, up to 2.5 tons of waste rock can be on the conveyor in 1 second, which is a serious problem.

For optimal loading of the main conveyor, as shown by simulation, it is very important to maintain a given output from each section, but there is a problem here also. This is the use of a vibratory feeder for supplying the rock mass from the section window to the conveyor, as it is installed in a confined space, on which presses the entire mass of rock above the feeder’s window, which makes it impossible
to use standard weight sensors and other similar devices, all this is complicated by restricting explosion fireproof demands for the measuring device. At the moment, the project is considering the assessment of the vibrating feeder loading process using optical control systems for moving objects [17]. It is also difficult to observe the goaf part of the longwall, since it is possible for the non-collapsed roof to hang there, which, as model experiments show, can be prevented by changing the outlet algorithms at adjacent sections.

The scientific novelty of the research results consists in the development of a technique for robotic estimation of the volume and composition of rock mass when the section feeder lets it out; in obtaining the support section outlet process optimal modes’ dependence on the volume and composition estimation data provided by means of technical vision; in substantiating the basic technological requirements to the design of complexes with release to the face conveyor robotics elements.

3. Conclusion
The obtained scientific results in the form of an IDEF0 scheme for the decomposition of the outlet process in key tasks (robotization: rock-coal, load amount, initiation); outlet control system operation algorithms; methods for assessing the volume and composition of the rock mass when the section is released by the feeder; technological requirements for the robotic complexes with controlled coal outlet creation; functional diagrams of the robotics of the support section feeder allowing, according to the authors, to solve the problem of the practical implementation of geotechnologies for the integrated development of mineral resources on the basis of promising software and hardware systems integrated into the general management system of the mining enterprise.

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References
[1] Goosen Ye V, Kagan E S et al 2020 Smart Innovation, Systems and Technologies pp 138–148
[2] Nikitenko S M and Goosen Ye V 2017 Mineral resources of Russia. Economics and Management 1 27–32
[3] Order of the Government of the Russian Federation of June 24, 2014 No. 1099-r “Russia’s coal industry development programs for the period until 2030”
[4] Brokk history https://www.brokk.com/about-brokk/history
[5] Thring M 1977 UK Study: Remote – Controlled Miner. Coal Age 6 16–22
[6] Koniukh V L and Tailakov O V 1991 Predesign Analysis of Mine Robotic Systems (Novosibirsk: Nauka, Siberian Branch) pp 9–15
[7] Kiklevich Yu N 1987 Mine Robotics (Kiev: Tekhnika) pp 48–65
[8] SME Mining Engineering Handbook 2011 ed P Darling (Society for Mining, Metallurgy and Exploration Inc.) pp 808–812
[9] Gill P, Hatfield M et al 2015 Conference: 51st AIAA/SAE/ASEE Joint Propulsion Conference (Orlando) 4111
[10] Reuter M, Krach M et al 2017 Fundamental and Applied Issues of Mining No 2 Vol 4 263–269
[11] The Principle of Longwall Top Coal Caving (LTCC) https://www.youtube.com/channel/UCjYrT--TpOrA86Iw_PkoVJw?&ab_channel=CaterpillarGlobalMining
[12] Klishin, V I, Anferov B A and Kuznetsova L V 2017 Innovations in the Fuel and Energy Complex and Mechanical Engineering (Fuel and Energy Complex-2017) (Kemerovo: KuzSTU) pp 57–63
[13] Nikitenko M S and Kizilov S A 2019 High-tech Technologies for the Development and Use of Mineral Resources (Novokuznetsk: SibSIU) pp 257–263
[14] Starodubov A N, Zinoviev V V and Klishin V I 2019 Science Intensive Technologies for the Development and Use of Mineral Resources (Novokuznetsk: SibSIU) pp 253–257
[15] Klishin V I, Kokoulin D I et al 2012 Patent for Invention RUS 2513952 12.26.2012
[16] Kizilov S A , Nikolaev P I et al 2017 Proc. of the XI All-Russian Sci. and Pract. Conf. in Automation Systems in Educ., Sci. and Prod. (Novokuznetsk: SibSIU) pp 241–245
[17] Shubnikova I S and Plaguta K A 2013 Proceedings of the Reliability and Quality International Symposium (Penza: Penza State University) pp 352–355