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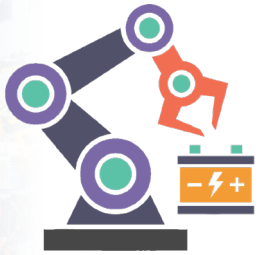

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Development of an Expert System for Fixing and Maintaining Mine Workings in the Mining Industry

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Abstract. *The article is devoted to the development of an expert system, the purpose of which is to optimize the processes of fixing and maintaining mine workings in the mining industry. The paper presents a comprehensive approach based on the application of theoretical, numerical-analytical and empirical research methods, as well as the systematization of primary data and in-depth analysis of the problem. The expert system is developed using modern object-oriented programming languages, which ensures high efficiency and flexibility of the system. The main objective of the system is to provide sound solutions for fixing and maintaining mine workings, depending on the types of rocks and mining conditions. Thus, the expert system allows to reduce the decision-making time in the process of fixing and maintaining mine workings. This is especially important in a dynamically changing mining industry. The development and implementation of an expert system allows you to increase the level of knowledge and skills of specialists in the industry. Interactive interaction with the system contributes to the exchange of experience and the accumulation of knowledge.*

Keywords: *expert system, neural networks, mining, knowledge base, software, deformation, fastening, fastening methods.*

The mining industry plays the key role in the global economy, providing a significant share of essential natural resources. However, mining involves a number of complex challenges, including supporting mine workings. These processes are inextricably linked to worker safety and the long-term sustain-

ability of mines and tunnels. This article examines the role of expert systems in providing solutions on the issues of supporting mine workings.

Expert systems are a modern form of artificial intelligence designed to make decisions in specific areas based on the knowledge and experience of experts in a given field. They use knowledge bases and algorithms to analyze the information and to formulate recommendations or decisions. An important characteristic of expert systems is their ability to explain decisions, which allows better understanding processes and results by the user.

Mining workings, such as shafts, mines and tunnels require reliable support systems to ensure worker safety, to prevent collapses and to improve work productivity. Traditional supporting methods, such as the use of metal beams, concrete pillars, and rock anchorages, although effective, cannot be optimal in different conditions and rock types [1].

The use of expert systems in the field of supporting mine workings provides several important advantages.

When using expert knowledge, mining experts can contribute their experience and knowledge to the expert system database. This allows using accumulated knowledge to make decisions in real time.

With an individual approach, expert systems can take into account various conditions and characteristics of each mine, which makes it possible to provide individual recommendations and solutions.

The speed and efficiency of expert systems running on high-speed algorithms that allow analyzing and providing solutions much faster than traditional methods.

Automation of processes using expert systems makes it possible to implement many processes associated with supporting mine workings, reducing the risks of human intervention.

Technologies and innovations in expert systems for the mining industry allow developing modern technologies and innovations that can be implemented in the field of systems for supporting mine workings.

Integration of sensors and monitoring systems to measure stress, strain and other parameters of mine workings provide real data for analyzing and decision-making with the use of machine learning methods that allow continuous improving the system, taking into account new data and experience. Robots and autonomous devices can perform supporting tasks in hazardous environments without human intervention. Modeling and simulating systems will make it possible to predict the behavior of mine workings and to optimize the supporting processes.

Research methods and stages of their implementation

The research goals will be achieved through an integrated approach to solving the assigned problems based on the use of theoretical, numerical-analytical and empirical methods with the in-depth analysis of the problem and systematization of primary source data with the development of requirements and special software.

The methodology of scientific research is based on the scientific developments of highly qualified specialists in the field of mining and information technology of the Republic of Kazakhstan, the Russian Federation, and non-CIS countries [2].

The development of algorithms and expert system modules will be implemented in modern object-oriented programming languages.

When carrying out studies, the main stages of developing expert systems will be performed: identification, conceptualization, formalization, implementation, testing and trial operation [3].

At the identification stage, the tasks to be solved will be clarified, experts and categories of users will be identified.

At the conceptualization stage, a meaningful analysis of the problem area will be carried out, the concepts used and their relationships will be identified, and methods of solving problems will be determined.

At the formalization stage, the ways of representing all the types of knowledge will be determined, basic concepts will be formalized, methods of interpreting knowledge will be determined, and the adequacy of the system of fixed concepts, solution methods, means of representing and manipulating knowledge will be assessed.

At the implementation stage, experts will populate the system's knowledge base. For this purpose, in addition to members of the research group, independent experts from scientific and design organizations in Kazakhstan and foreign countries will also be involved. At this stage, a prototype of the expert system will be developed. The development of a prototype will consist of programming its components or selecting them from the existing intelligent systems and filling them with a knowledge base [4].

At the testing stage, independent experts will interactively, using dialogue tools, check the adequacy of the expert system.

At the trial operation stage, the suitability of the expert system for end users will be tested.

Today, the mining software market includes a significant number of companies offering a variety of products. Among the main market participants in the CIS countries are such companies the Gemcom Software International Inc. (Canada), the Datamine-Mineral Industries Computing Ltd (UK), the Surpac Software International (Australia), the Micromine Pty Ltd (Australia), the Mintec Inc. (USA) and others.

The similarity between the software packages of these companies lies in the fact that they provide approximately the same set of functions. The existing software for mining enterprises can be divided into three classes based on the cost and availability:

- publicly available programs that can be obtained for free, for example, via the Internet;
- commercial programs in the low- and mid-price range provided by small specialized companies;

- integrated systems covering the full cycle of operations from processing primary geological information to developing ready-made drawings for quarries or mines.

The proposed expert system being developed belongs to the second class. At the moment, there are practically no companies in Kazakhstan specializing in the development of expert systems for mining enterprises on a scientific basis. In most cases, the development of such systems is carried out only by research organizations that receive orders from government agencies or attract grant funding.

However, the growing need for such systems is significant. The increasing complexity of mining processes and complex mining and geological conditions require accurate calculations and design of mining operations. In this context, an expert system can be a valuable tool for providing solutions depending on mining, geological and technological parameters.

Let us give several practical examples of developing expert decision-making systems on the issues of supporting mine workings.

A system for supporting mine workings based on monitoring the data and using an expert system to analyze the data received from monitoring sensors in the mine. The system will use the information of stresses, strains and the other parameters of mine workings to determine optimal methods and parameters for supporting. Machine learning algorithms will allow updating the system continuously and taking into account new data and experience, which will optimize supporting processes and prevent possible emergency situations.

An expert system for selecting the optimal supporting material will help engineers selecting the most suitable supporting material for specific rock stabilization and mining conditions. The system will use a constantly updated database with the information of various materials and their characteristics. When entering the data of the rock and the required characteristics of the supporting element, the system will provide recommendations for selecting the optimal supporting material.

The robotic expert system for supporting in tunnel construction can be integrated with robotic devices to automate supporting processes. The robots will be equipped with sensors and surveillance cameras to collect operational data of the condition of the rock and to select optimal anchorage methods. The expert system will control robots and make decisions based on monitoring data and expert knowledge.

An expert system for simulating the behavior of mine workings using the modeling and simulating technology to predict the behavior of rocks and mine workings under various loading and support scenarios. At this, engineers will be able to run various simulations and experiments to evaluate the effectiveness of different supporting methods and to select the most suitable option for each specific situation.

All these case studies presented demonstrate how expert systems can be used in the mining industry to improve mine safety, efficiency and sustainability. These systems help making informed and optimal decisions based on the knowledge and experience of experts in the field.

Scientific results

An expert system based on the knowledge and experience of mining experts will optimize selecting the anchorage and support methods for different rock types and conditions. This helps to increase the work efficiency and to improve safety in the mining industry.

Thanks to the use of an expert system, the supporting processes will be more accurate and adapted to the specific conditions of the mine. This will help increasing reliability and durability of mines, pits and tunnels.

The expert system will use a knowledge base containing experimental data with an assessment of expert recommendations. This approach will allow making informed decisions and proposing the optimal anchorage and support options based on evidence [5].

The expert system automates the processes of analyzing and decision-making, which speeds up information processing and reduces reaction time to changes in conditions and situations in mining operations [6].

Developing an expert system facilitates the integration of new technologies such as machine learning, robotics, and monitoring systems, which can lead to more advanced and automated support methods.

The expert system allows selecting the optimal support methods depending on the characteristics of the rock and mining conditions.

Let R be the strength rating of the rock, H the depth of the mine opening, and F the load on the mine opening. Then the formula for determining the optimal type of the supporting system is presented as follows:

Supporting_system_type = function (R, H, F).

The scientific result consists in the development of algorithms and formulas that take into account physical, mechanical and strength properties of rocks and allow determining the most suitable type of supporting elements.

The expert system makes it possible to predict the stress-strain state of the rock massif around mine openings under various conditions and load characteristics. The scientific result is the development of models and formulas based on the mechanics of a deformable solid body to predict deformations depending on the parameters of mine workings.

Let E be the modulus of elasticity of the rock, S the cross-sectional area of the mine opening, P the load on the mine opening. Then the formula for determining the deformation is presented as:

Deformation = (P * L) / (E * S), where L is the length of the mine opening.

```python
def optimal_krepezh(R, H, F):
    # Реализация алгоритма для определения оптимального типа
    # Вернуть результат в зависимости от значений R, H и F
    # Например, для простоты, предположим, что при R > 1000,
    # в противном случае используем тип "B"
    if R > 1000 and H > 500 and F < 200:
        return "A"
    else:
        return "B"
```

Figure 1 – Example of the program code: optimization of the support selection

```python
def deformation_prediction(E, S, L, P):
    # Расчет деформации на основе формулы: (P * L) / (E * S)
    deformation = (P * L) / (E * S)
    return deformation
```

Figure 2 – Example of the program code: justification of the predicted deformations

The expert system will allow optimizing the cost of fastening materials when performing work on fastening and maintaining mine workings. The scientific result is the development of algorithms and formulas that take into account the parameters of mine workings and types of supports to minimize the costs.

Let V be the volume of mining, C the cost of a unit of supporting material. Then the formula for determining the cost of supporting materials is presented as:

$$Costs = V * C.$$

The presented formulas demonstrate that the development of an expert system for supporting mine workings contributes to the development of mathematical models and algorithms that help optimizing processes and make informed decisions based on the data and the experience of experts in the field.

Thanks to a more accurate and predictable approach to supporting mine workings, the working conditions for workers will improve ensuring safety and reducing the risk of accidents.

For an expert system for supporting mine workings, the interface must be intuitive, easy to use and have all the necessary functions to interact with users. Here is an example of a simple text interface that could be used for such a system.

After the user selects an option, the system can provide additional hints or request additional information to complete the selected task, for example, for the option of «Calculating optimal supports». Thus, the user interacts with the system, providing the necessary information, and receives back optimal decisions, forecasts or recommendations for supporting mine workings in the mining industry. The interface will be supplemented with graphic elements, graphs and tables for more convenient display of results and data visualization.

In the main, the development of an expert system for supporting mine workings in the mining industry will help improving the efficiency and safety of production processes, and will also bring innovation to modern technologies in this important industry.

Conclusions

The development of an expert system makes it possible to optimize the processes of supporting mine workings. Using the knowledge and experience of experts in combination with modern technologies allows making informed and effective decisions. The expert system helps improving safety in the mining industry. Solutions that are accurate and tailored to mining conditions help preventing accidents and reducing risks for workers.

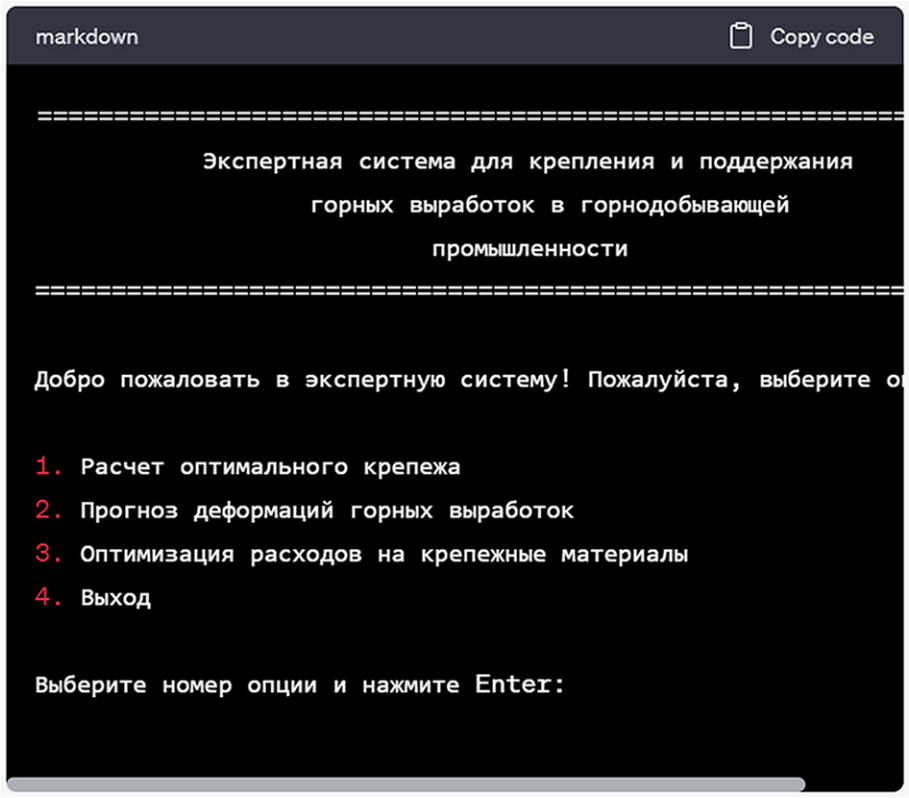

Figure 3 – Example of the program code

Thanks to the use of an expert system, mine workings receive a more reliable and durable support system. This helps extending the life of the infrastructure and reduces the need for regular repairs.

The development of an expert system promotes the integration of modern technologies and innovations in the mining industry. The introduction of new methods such as machine learning and robotics allows for more efficient and automated processes.

The expert system allows reducing decision-making time in the process of supporting mine workings. This is especially important in the dynamically changing mining industry. The development and implementation of expert systems allows increasing the level of knowledge and qualifications of specialists in the industry. The interaction with the system facilitates the exchange of experience and accumulation of knowledge.

In summary, the development of an expert system for supporting mine openings in the mining industry represents a significant step in improving production processes, increasing safety and introducing innovations to this industry. Its successful implementation can lead to reduced risks and economic benefits for mining companies.

Expert systems are becoming an integral part of the modern mining industry, providing innovative and optimal solutions for supporting mine workings. The use of expert knowledge, machine learning, robotics and simulation can improve the safety, efficiency and sustainability of mines, which is critical to the success of the mining industry and society as a whole.

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REFERENCES

1. Халкечев Р.К. Экспертная система управления процессом научных исследований разрушения геоматериалов различных порядков сложности // ГИАБ. 2015. № 9. URL: https://cyberleninka.ru/article/n/ekspertnaya-sistema-upravleniya-protsessom-nauchnyh-issledovaniy-razrusheniya-geomaterialov-razlichnyh-poryadkov-slozhnosti Кравченко Т.К. Системы поддержки принятия решений: учеб. и практ. для вузов / Т.К. Кравченко, Д.В. Исаев. – М.: Изд-во Юрайт, 2022. – 292 с.
2. Шогенова З.А., Крымшокалова Д.А., Шереужева М.А. Информационное обеспечение системы, использующей DLL библиотеки учёта параметров режима оптимизации процессов горных работ // Вестник Кузбасского государственного технического университета. 2020. № 5 (141). – С. 47-54.
3. Чалыкина, Е.Г. Разработка экспертных систем / Е.Г. Чалыкина, И.В. Сухан. – Текст: непосредственный // Молодой ученый.

2019. № 16 (254). – С. 16-21. URL: https://moluch.ru/archive/254/58317.
4. Козлова, Т.Д. Использование оболочек для программной реализации экспертной системы поддержки процесса диагностирования автоматических станочных модулей / Т.Д. Козлова. – Текст: непосредственный // Молодой ученый. 2017. № 2 (136). С. 110-113. URL: https://moluch.ru/archive/136/38023.
5. Дошина, А.Д. Экспертная система. Классификация. Обзор существующих экспертных систем / А.Д. Дошина. – Текст: непосредственный // Молодой ученый. 2016. № 21 (125). С. 756-758. URL: https://moluch.ru/archive/125/34485/.
6. Яворский В.В., Демин В.Ф., Смагулова А.С., Мифтахов Р.Р. Интеллектуальные информационные системы в горном деле: Учебное пособие. Караганда: Изд-во КарГТУ, 2008.
7. Демин В.Ф. и др. Технология управления устойчивостью приконтурного углепроводного массива горных выработок: Монография. Караганда: Изд-во КарГТУ, 2013. – 381 с.

Тау-кен өнеркәсібіндегі тау-кен қазбаларын бекіту және қолдау үшін сараптамалық жүйені әзірлеу

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***Аңдатпа.** Мақала тау-кен өнеркәсібіндегі тау-кен қазбаларын бекіту және қолдау процестерін оңтайландыруға бағытталған сараптамалық жүйені әзірлеуге арналған. Жұмыста зерттеудің теориялық, сандық-аналитикалық және эмпирикалық әдістерін қолдануға, сондай-ақ бастапқы деректерді жүйелеуге және мәселені терең талдауға негізделген кешенді тәсіл ұсынылған. Сараптамалық жүйе жүйенің жоғары тиімділігі мен икемділігін қамтамасыз ететін заманауи объектіге бағытталған бағдарламалау тілдерін қолдана отырып жасалады. Жүйенің негізгі міндеті тау жыныстарының түрлеріне және өндіру жағдайларына байланысты тау-кен қазбаларын бекіту және қолдау бойынша негізделген шешімдерді ұсыну болып табылады. Осылайша, сараптамалық жүйе тау-кен қазбаларын бекіту және жөндеу процесінде шешім қабылдау уақытын қысқартуға мүмкіндік береді. Бұл әсіресе динамикалық өзгеріп жатқан тау-кен өнеркәсібінде маңызды. Сараптамалық жүйені әзірлеу және енгізу сала мамандарының білім деңгейін және біліктілігін арттыруға мүмкіндік береді. Жүйемен интерактивті өзара әрекеттесу тәжірибе алмасуға және білім жинақтауға ықпал етеді.*

***Кілт сөздер:** сараптамалық жүйе, нейрондық желілер, тау-кен өндірісі, білім базасы, бағдарламалық қамтамасыз ету, деформация, бекіту, бекіту әдістері.*

Разработка экспертной системы для крепления и поддержания горных выработок в горнодобывающей промышленности

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***Аннотация.** Статья посвящена разработке экспертной системы, целью которой является оптимизация процессов крепления и поддержания горных выработок в горнодобывающей промышленности. В работе представлен комплексный подход, основанный на применении теоретических, численно-аналитических и эмпирических методов исследования, а также систематизации первичных данных и углубленного анализа проблемы. Экспертная система разрабатывается с использованием современных объектно-ориентированных языков программирования, что обеспечивает высокую эффективность и гибкость системы. Основной задачей системы является предоставление обоснованных решений по креплению и поддержанию горных выработок в зависимости от типов горных пород и условий добычи. Таким образом, экспертная система позволяет сократить время принятия решений в процессе крепления и поддержания горных выработок. Это особенно важно в условиях динамично изменяющейся горнодобывающей промышленности. Разработка и внедрение экспертной системы позволяет повысить уровень знаний и квалификации специалистов в отрасли. Интерактивное взаимодействие с системой способствует обмену опытом и накоплению знаний.*

Ключевые слова: *экспертная система, нейронные сети, горная выработка, база знаний, программное обеспечение, деформация, крепление, методы крепления.*

REFERENCES

1. Halkechev R.K. Jekspertnaja sistema upravlenija processom nauchnyh issledovanij razrushenija geomaterialov razlichnyh porjadkov slozhnosti. GIAB. 2015. No. 9. URL: https:.cyberleninka.ru/article/n/ekspertnaya-sistema-upravleniya-protsessom-nauchnyh-issledovaniy-razrusheniya-geomaterialov-razlichnyh-poryadkov-slozhnosti Kravchenko T.K. Sistemy podderzhki prinjatija reshenij: ucheb. i prakt. dlja vuzov / T.K. Kravchenko, D.V. Isaev. – Moscow: Publ. Jurajt, 2022. 292 p.
2. Shogenova Z.A., Krymshokalova D.A., Shereuzheva M.A. Informacionnoe obespechenie sistemy, ispol'zujushhej DLL biblioteki uchjota parametrov rezhima optimizacii processov gornyh rabot. Vestnik Kuzbasskogo gosudarstvennogo tehnicheskogo universiteta. 2020. No. 5 (141). Pp. 47-54.
3. Chalykina, E.G. Razrabotka jekspertnyh sistem / E.G. Chalykina, I.V. Suhan. – Tekst: neposredstvennyj. Molodoj uchenyj. 2019. No. 16 (254). Pp. 16-21. URL: https://moluch.ru/archive/254/58317.
4. Kozlova, T.D. Ispol'zovanie obolochek dlja programmnoj realizacii jekspertnoj sistemy podderzhki processa diagnostirovanija avtomaticheskih stanochnyh modulej / T.D. Kozlova. – Tekst: neposredstvennyj. Molodoj uchenyj. 2017. No. 2 (136). Pp. 110-113. URL: https://moluch.ru/archive/136/38023.
5. Doshina, A.D. Jekspertnaja sistema. Klassifikacija. Obzor sushhestvujushhih jekspertnyh sistem / A.D. Doshina. – Tekst: neposredstvennyj. Molodoj uchenyj. 2016. No. 21 (125). Pp. 756-758. URL: https://moluch.ru/archive/125/34485/.
6. Javorskij V.V., Demin V.F., Smagulova A.S., Miftahov R.R. Intellektual'nye informacionnye sistemy v gornom dele: Uchebnoe posobie. Karaganda: Publ. KarGTU, 2008.
7. Demin V.F. i dr. Tehnologija upravlenija ustojchivost'ju prikonturnogo ugleprovodnogo massiva gornyh vyrabotok: Monografija. Karaganda: Publ. KarGTU, 2013. – 381p.