Application of Artificial Intelligence to Improve the Efficiency of Monitoring and Diagnosing the Condition of Complex Technical Objects

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***Abstract*—This article is devoted to a study on the use of distributed regulators in conjunction with an intelligent decision support system in the context of the operation of a hydromineral well in the Caucasus Mineral Waters region. Hydromineral raw materials play an important role in the medical and recreational industry, and the optimization of its extraction processes is a critical issue to ensure the quality and sustainability of production. The article presents an approach based on the joint use of distributed regulators and intelligent decision support system in order to increase the efficiency and reliability of the process of obtaining hydromineral raw materials. The integration of these technologies makes it possible to automate and optimize well management, taking into account difficult geological conditions.**

Keywords—hydromineral raw materials, producing well, distributed regulators, intelligent decision support system, well operation, production optimization, resource management, data analysis, control automation.

I. INTRODUCTION (*HEADING 1*)

The extraction of hydromineral raw materials is a key industry in the Caucasian Mineral Waters region and is of strategic importance for both the medical and recreational industries. Geological features, fluctuations in aquifer characteristics and changing environmental requirements pose challenges to efficient and sustainable industrial management. This article presents a study on the application of an innovative approach combining distributed controllers and intelligent decision support systems (IDSS) in the context of operating a hydromineral production well. The purpose of this study is to demonstrate how the combined use of distributed regulators and IDSS can significantly improve the efficiency of hydromineral production management, reduce the risks of well loss and ensure compliance with environmental regulations. This study may have important implications for geology and natural resource management professionals, as well as those interested in sustainable and efficient hydromineral extraction. The relevance of this topic lies in the fact that in industry there is a huge variety of different sensors and devices, thanks to which most of the production is automated; there are tasks that still require human activity. The use of AI will significantly increase the efficiency of monitoring and diagnosing the condition of complex technical objects.

II. REVIEW OF THE STATE OF THE ART IN THE SUBJECT AREA

Industry is becoming increasingly digital; the digital enterprise is already a reality [1]. Data is continuously generated, processed and analyzed. Volumes of data in manufacturing environments are the foundation upon which digital representations of entire plants and systems are created [2]. If machines and processes could independently gather information from these large volumes of data and optimize their processes while running in real time, the potential would be enormous [3]. The good news is that this can already be achieved, step by step, using intelligent systems based decision support. Decision support systems (DSS) are actively used in all spheres of human life [4]. They are especially common when processing large data sets, predicting processes, and providing information support to decision makers. The existing DSS is based on artificial intelligence methods that provide collection, processing, summarizing information about the state of objects (processes) and predicting their future state. The task of implementing systems using artificial intelligence (AI) is divided into two stages [5]. The first step is to build a classification model, usually using neural networks and a deep machine learning (ML) process.

The result of MO is: model structure; multipliers (weights) that determine the probabilities of obtaining classification categories from the data set on which a specific model is trained [6]. At the second stage, the resulting model is applied to new data.

III. STATEMENT OF THE PROBLEM AND METHOD OF ITS SOLUTION

Detecting faults in mechanical equipment is a major problem in many industries [7]. Most failures are likely to occur under operating conditions, resulting in significant increases in operating costs. Moreover, unpredictable faults can lead to equipment failure or even jeopardize human safety. Once a mechanical component detects a fault, it soon starts a chain reaction and damages other components [8]. Understanding the condition of the equipment and its components is indispensable. This would reduce unexpected costs, increase equipment life and improve safety by identifying faulty components [9]. Both normal and abnormal operation of mechanical systems consisting of rotating components can be investigated through vibration signal analysis [10]. Therefore, vibration analysis plays an important role in monitoring the machine condition and diagnosing its malfunction. Analysis will be carried out to study different types of systems consisting of several mechanical components, such as gears and bearings, by measuring vibration levels using sensors such as accelerometers [11].

When studying the use of distributed controllers together with an intelligent decision support system in the context of the extraction of hydromineral raw materials in the Caucasian Mineral Waters region, the following methods were applicable:

- Geological analysis: study of the geological structure and characteristics of the region's aquifers.
- Data collection and analysis: collection of production data, including energy costs, water chemistry,

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production volumes and other parameters. Analysis of this data helped determine current processes and their effectiveness [12].

- Environmental assessment: assessing the impact of mining on the environment and developing measures to comply with environmental standards.
- Economic analysis: analysis of costs and benefits from the use of distributed regulators and ISDS, including calculation of return on investment.
- Comparative analysis: comparison of the results of using distributed regulators and ISSPR with traditional methods of managing the production of hydromineral raw materials.
- Building forecast models.
- Conducting multiple correlation and regression analysis.

IV. Conducting Research

The first step to improving the effectiveness of advancing a research idea into practice is to have a good understanding of the current operational regime of industrial R&D. In order to understand how artificial intelligence will affect complex technical objects, it was decided to analyze the demand for units that monitor operation using the example of a producing well. The following factors were taken (Table 1). It is worth noting that the statistics were calculated for 11 months of operation, since the plant did not produce hydromineral raw materials for one month.

y – percentage of participation of the technical department in the repair or debugging of equipment, %;

x1 - performance improvement, relative unit of measurement (oei);

x2 - improving processing quality, oei;

x3 - reduction of the human factor, oei;

x4 – increasing the versatility of work, oei;

x5 - cost reduction, oei.

TABLE I. Initial Data for Correlation and Regression Analysis

№ п/п	y	x_1	x_2	x_3	x_4	x_5
1	5,1	0,21	0,23	0,01	0,21	0,01
2	5,0	0,22	0,24	0,01	0,01	0,01
3	5,4	0,22	0,25	0,01	0,01	0,02
4	4,8	0,22	0,25	0,02	0,01	0,02
5	5,0	0,24	0,25	0,03	0,02	0,02
6	5,3	0,24	0,25	0,05	0,03	0,03
7	5,7	0,24	0,25	0,05	0,05	0,03
8	5,8	0,25	0,26	0,06	0,04	0,03
9	6,0	0,25	0,26	0,06	0,04	0,05
10	6,2	0,26	0,25	0,06	0,06	0,05
11	6,8	0,26	0,26	0,07	0,06	0,05
12	7,1	0,27	0,27	0,08	0,08	0,07

Next, regression analysis was carried out to build a model

The next step was to create a multiple regression equation:

$$\hat{y}_x = 1,78 + 4,10x_1 + 6,9x_2 + -10,4 + 1,86x_4 + 47x_5 \quad (1)$$

Regression coefficients show the average change in the resulting characteristic with a change of 1 unit of its measurement of this factor, provided that all others are constant.

The next step is to give a comparative assessment of the strength of the relationship between factors and the result using average (general) elasticity coefficients [13].

Based on the values of the average elasticity coefficients, we can conclude that the characteristics of factors x_2 and x_5 have a stronger influence on the result y than the characteristics of factors x_2, x_3 and x_4.

Next, the significance of the linear regression equation and the connection strength indicator was assessed using the Fisher-Snedecor F distribution.

According to the variance analysis tables, $F_{факт}$=19,57. The probability of accidentally obtaining such an F distribution value is 0.0002, which does not exceed the acceptable significance level of 5%; This is evidenced by the P value - the value from the same table. Therefore, the obtained value is not accidental; it was formed under the influence of significant factors, that is. the statistical significance of the entire equation and the indicator of tightness of connection therefore the regression equation is statistically significant. After evaluation using the Fisher-Snedecor F distribution, the statistical significance of the regression coefficients was assessed using Student's t test [14].

Next, the average approximation error was calculated using the simple arithmetic average formula:

$$\overline{A} = \frac{1}{n}\sum \left|\frac{y-\hat{y}_x}{y}\right| \cdot 100\% = 4,37\% \quad (2)$$

Thus, the actual values of the resulting characteristic differ from the theoretical values by 4.37%. Therefore, the constructed model is satisfactory [15]. The next step was to calculate the matrix of paired correlation coefficients. Figure 1 shows the matrix of pairwise correlation coefficients.

	y	x1	x2	x3	x4	x5
y	1					
x1	0,849971	1				
x2	0,742813	0,837972	1			
x3	0,874628	0,968989	0,855491	1		
x4	0,135827	-0,15653	-0,26953	-0,03125	1	
x5	0,962091	0,918619	0,802845	0,937143	0,031248	1

Fig. 1. Pair correlation coefficient matrix.

When selecting factors for the model, preference is given to the factor that, while quite closely related to the result, has the least close connection with other factors. In our example, we find that the informative factors are: x_1 and x_5.

The last step was to calculate the average approximation error. The actual values of the resulting characteristic were obtained, which differ from the theoretical values by 0.06%. Therefore, the constructed model is satisfactory and statistically significant [16].

The next stage was a study that allowed us to test the hypothesis for the presence of a trend, namely the frequency of equipment breakdowns.

Having studied the statistical data of production indicators of complex technical objects using the example of the operation of a production well, a dynamic series was generated for the period October 2020 – September 2022.

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Next, predictive models are built:

1. linear model;

2. exponential model;

3. hyperbolic model of type I;

4. hyperbolic model of type II.

Having selected the optimal forecast model based on the coefficient of determination, it was concluded that linear, exponential and hyperbolic of the second type are acceptable for making a forecast, but the exponential model has the largest (closest to unity) coefficient of determination. In Figure 2 you can see the exponential model.

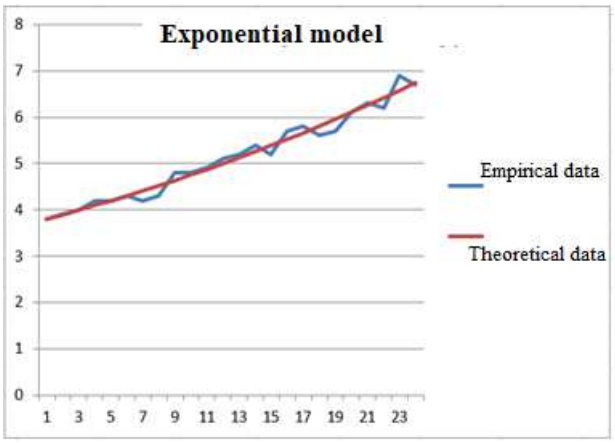


Fig. 2. Graphs of distribution of initial data and exponential model.

V. Research results

During the research, a predictive model was defined that more accurately describes the dynamics of equipment reliability and is based on an exponential function. In addition, we conducted a correlation and regression analysis to evaluate the impact of various factors on equipment reliability. Based on this analysis, it was concluded that the most important factors affecting equipment reliability include improving processing processes, reducing maintenance costs, and optimizing the use of human resources. Thanks to AI, these factors can be minimized.

Detection of defects in mechanical equipment is a serious problem in various industries. Many faults, as a rule, arise during operation, which leads to a significant increase in costs. Moreover, unexpected failures can lead to equipment failure and even threaten the safety of personnel. When one mechanical part becomes faulty, it often starts a chain reaction that can lead to damage to other components. As part of the study, a predictive model was developed that more accurately describes the dynamics of resistance to equipment failures based on an exponential model. A multivariate correlation and regression analysis of factors was also carried out, which made it possible to identify the most significant influencing factors [17]. According to the findings of the study, among such factors it is necessary to highlight the improvement of the quality of processing and the reduction of equipment maintenance costs, as well as the optimization of the use of human resources. If you develop an intelligent system and connect it with distributed controllers, it can optimize the operation of equipment and processes, which allows you to achieve maximum productivity at minimal cost. Reducing the downtime of equipment and processes can significantly increase the manufacturer.

VI. Research results

The results of the study related to the implementation of an intelligent system with distributed regulators in the extraction of hydromineral raw materials in the Caucasian Mineral Waters region may be important for science and engineering for the following reasons:

1. development of control technologies: the study raises the question of the use of modern technologies, such as intelligent systems and distributed controllers, in the field of natural resource extraction. This can contribute to the development and improvement of approaches to managing complex production processes;

2. application in ecology: optimization of the extraction of hydromineral raw materials, taking into account environmental factors, is becoming an increasingly relevant topic in the modern world. The results of the study can help improve the sustainability of production and reduce negative environmental impacts;

3. research in the field of resource management: The research covers issues of energy, financial and human resource management. This has applications not only in the field of hydromineral extraction, but also in other industries where resources play an important role;

4. safety and industrial reliability: results on the prevention of malfunctions and accidents in production can attract the attention of researchers in the field of safety and reliability of industrial systems;

5. multivariate data analysis: the study includes multivariate correlation-regression analysis, which can be a useful method in other scientific and engineering studies that require analysis of the influence of many factors;

6. application of machine learning: further research includes the application of machine learning techniques, this can be a valuable contribution to the field of artificial intelligence and data analytics.

Thus, the results of further research can be considered relevant and valuable both in the scientific community and in the engineering field.

VII. Conclusions based on the results obtained

In conclusion, the presented study is only the first step in an extensive research plan. The results and conclusions obtained provide a basic understanding of the issues discussed, but leave many aspects open for further and more in-depth study. This work provides a foundation for future research, which may include expanded analysis, additional methodologies, and in-depth consideration of the identified trends. Thus, this study represents only the first chapter in a larger scientific narrative designed to expand our knowledge in this area [18].

During the research, a predictive model was defined that more accurately describes the dynamics of equipment reliability and is based on an exponential function. In addition, correlation and regression analysis was carried out to evaluate the influence of various factors on equipment reliability. Based on this analysis, it was concluded that the most important factors affecting equipment reliability include improving processing processes, reducing maintenance costs, and optimizing the use of human resources. Thanks to AI, these factors can be minimized [19].

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One of the key functions of an intelligent system during well operation is the aggregation and translation of massive data streams coming from tens of thousands of devices.

Automated processing of information from sensors directly at the fields provides the most up-to-date information about reserves, production needs and equipment condition. This increases the ability to detect device failures early, optimize management, and make the most of key assets while ensuring interoperability across decentralized control systems. All this will help avoid critical system failures.

I study this area and literature sources, and the following conclusions can be drawn:

1. the introduction of intelligent systems in the operation of production wells is a promising area that is rapidly developing along with other modern areas of information technology in the industrial sector;

2. the expected growth of technology will allow the mass introduction of “smart” components into many industrial facilities, such as sensors, controllers, units, parts, products, and so on, at a relatively low cost;

3. this trend will provide the technical ability to design completely decentralized systems with built-in self-organization capabilities;

4. modern intelligent systems can help in forecasting during the operation and selection of mining sites;

5. Intelligent systems technologies can become the basis for the development of such systems and become the key point of the intelligent component of each distributed object;

6. thanks to the intelligent system, it is possible to monitor and control the production of mineral water in real time, thereby reducing the risk of depletion, well collapse and increasing production efficiency.

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