N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 5, Number 443 (2020), 6 – 12 **https://doi.org/10.32014/2020.2518-170X.98**

UDC 519.7
IRSTI 52.13.19

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MODEL FOR DETERMINING CLASSIFICATION OF FILLING MATERIALS HARDENING

Abstract. This paper presents the model for solving the problem of classification of trajectories of development of states of filling material in the presence of a priori information on the trajectories of processes that have already passed the development of states of the processes. Consideration of the hardening process of stowage material as a chemical-technological process, which can be considered as a multi-parameter dynamic (time) series, allows us to determine the development class of the state of the material based on the classification of the state of the stowage. The proposed approach has established the fundamental possibility of using the proposed methodology to solve the problem of dividing given trajectories represented by time series into classes. It allows us to obtain a model that, according to formal rules, determines the classification of trajectories by sets of heterogeneous features of its state at certain time and improves the reliability of the classification.

Key words: forecasting, filling material, safety, dynamic (time) series, object recognition.

Introduction. Pattern recognition**,** or object classification (observations, phenomena, signals, situations, possesses) is one of the most dynamically developing spheres of applied mathematics and cybernetics which **is** caused by the constant demands of practice as it often faces rather complicated processes and phenomena. An excessive desire for accuracy has begun to exert an influence that negates control theory and system theory, since it leads to the fact that research in this area focuses on those and only those problems that can be precisely solved. Many classes of important problems in which data, goals, and constraints are too complex or poorly defined to allow accurate mathematical analysis, remained and remain aloof only because they cannot be mathematically interpreted [1,2]. The constructed mathematical models were either complex or too simple, which did not allow obtaining acceptable results. Therefore, in some cases, mathematical modeling is an art, and the quality of models largely depends on the intuition, skill and creativity of their developers. One approach to solving this kind of mathematical modeling problem is building recognition systems based on accumulated [3].

In connection with the expansion of the range of practical tasks, the set of heuristic (incorrect) recognition algorithms, the information for which is poorly formalized, is constantly growing. The idea of constructing a unified mathematical theory of incorrect recognition algorithms belongs to Yu. I. Zhuravlev and was developed in his works [4], one of which is “On the algebraic approach to solving recognition or classification problems”. These works give a description of the algorithms for computing estimates and present an algebraic approach to the construction of models of recognition algorithms.

In the framework of estimation calculation algorithms, an approach to solving the problems of determining the states of complex systems in the presence of a priori information about classes is proposed. The paper presents well-grounded algorithms for optimal object recognition.

Given the existence of a priori information about classes, this approach allowed solving a number of problems from a variety of poorly formalizable. But when solving practical problems, it's either impossible to obtain accurate a priori information about classes, or this requires large expenditures of resources, including computational. As a result, the task is to classify objects or observations that do not have the appropriate mathematical apparatus. The forecasting task posed in such a form, which determines the future state of the observed process of the object's functioning on the basis of taking into account information about past states of processes and its current data, belongs to the class of poorly informative dynamic problems.

In this paper, we consider a method with which to solve the problem of constructing a classification of states of dynamic objects in the absence of information about classes.

The aim of this work is to develop and study methods for classifying dynamic objects and determining the states of complex systems, in the absence of a priori information about classes that allow us to determine computational algorithms for optimal classification and forecasting that ensure stability and the required quality of recognition processes.

Since the '80s there have been undertaken attempts of joint image recognition and correlation - regressive analysis consideration for solving problems of various contents [5-11]. It was proposed that for various homogeneous groups the same signs influence on objective function on benchmark figure in varying degrees. Therefore, before appliance of regressive - correlation apparatus analysis it needs on initial stage to divide data on uniform classes and solve objective problem separately for each of the following classes. These attempts where productive due to appliance of image classification methods and they were found implementation in practical tasks - this is problem of classification as needed preliminary stage of statistical processing multidimensional data, it is classification in the tasks of optimal regulation and planning, it's task of classification in problems of forecasting economic - sociological situations or selected indicators and etc.

Successful appliance of image recognition methods in forecasting socio- economical situations problems and separate indicators gave basis to distribute that approach on other areas of knowledge with inclusion of their specific. For that, it was proposed to consider distribution on classes in other moments of time of processes development.

The paper proposes the formalization of the task of classifying the trajectories of development of states of filling materials used in the development of a number of mineral deposits in the presence of a priori information about the trajectories of processes that have already passed the development of states of processes.

This has become possible thanks to the successful use of pattern recognition methods, and the task of dividing trajectories into classes was used in the practical task of classifying dynamic processes as a necessary step in the processing of statistical information from multidimensional data.

Formulation of the problem. In a number of mineral deposits development, systems with stowing are used [12-14].

In mining stowing is defined as filling the goaf with stowing material, which is formed in the entrails of the earth as a result of mineral extraction. Stowing materials can be crushed rock formation, and production wastes. Stowing is solid if all the goaf is filled, and partial when certain parts (as tapes or layers) of it are filled. Depending on the way of transportation and stowage hydraulic, pneumatic, hydro-pneumatic, mechanical, self-flowing and manual are distinguished.

The use of stowing on mining enterprises caused by the process safety of the performance of mining operations, preservation of buildings on the surface of the earth, safety and the environment control, etc. For this purpose, goof is filled with stowing material, which is after reaching a certain state of the material should serve as supporting pillars.

The goals of the use of stowing material depend on the purpose. Stowing is used to control rock pressure, to reduce losses and dilution of extracted minerals in mining, to prevent mine fires, to reduce surface deformations of the earth and to protect the objects on the earth surface from damage, to improve the safety of mining operations, for improving the ventilation of underground workings, to reduce transport costs.

Requirements for filling properties can be different and depend on its purpose. Thus, the requirements for filling used to prevent subsidence of the earth surface and thus the protection of buildings and structures is much higher and it is especially important to forecast its states of stowing, than in cases when for example, stowing serves as the filler of voids and prevention of ore dilution and loss.

Depending on the purpose and field development systems dry, hydraulic, hardening and other stowing are used. It is reasonable that properties and methods of their creation are different. At hardening stowing binder component is added, that significantly increases the cost of stowing due to the high cost of binding material. This type of stowing greatly exceeds the cost of others and is used in strictly defined cases and only under condition of full recoupment of materials and works on the stowing. This is one of the reasons for considering this type of stowing.

There is a problem of definition of readiness of the state of hardening filling to perform intended functions [12-14].

Based on the above propositions, it can be stated that the determination of the state of the filling is an important and urgent problem, therefore there is a need to develop new ways and methods for determining the states of the technological process [12].

The usual practice of controlling the state of stowing is radiometric monitoring, local destruction methods, impact methods, an acoustic method, a method for measuring material temperature, etc.

The core element of the abovementioned methods is that they require creating individual gradation dependencies based on the results of studies of standard sample cubes made of concrete of the same composition and age as the object under study, the structure, in our case, filling. This directly measures some indirect physical characteristic related to the strength by correlation dependence. To establish this dependence, and, accordingly, to establish the strength of the structure, it is firstly necessary to establish a grading characteristic between strength and some indirect characteristic – temperature, humidity, conductivity, etc.

For that reason bringing durability dependence P array from its indirect characteristics, varying by time, - on basement of methods of least squares constructing dependence of chosen characteristics (temperature, humidity, acoustic parameter, electrical conduction and etc.) in discrete moments of time t_k on time interval $[t_0,t_M]$ with corresponding calculation of statistical parameters - dispersion, correlation coefficient, coefficient of determination and etc.

The values (characteristics) at the moment of time *t,* are taken as the parameters of the dynamic state of the filling at the moment of time *t*.

It should be noted that each characteristic separately determines the state of the filling not completely, but only one side of it, and cannot be an overall assessment of the dynamic state of the process.

Thus, the object of study has a set of the object characteristics, varying in time *t*.

In all cases, forecasting assessment of filling seems necessary to measure at different time points $T = \{t_1,...,t_T\}$ filling parameters characterizing the static state and the dynamics [2].

Below we give a possible way to create an apparatus for processing attributes of any type, and ways to apply this apparatus to the problems of classifying trajectories represented by time series based on the possibility of introducing a distance between different types of vectors.

Formalization of the problem statement. Accepting the approach and denotations from the works of Zhuravlev Yu. I., we give a description of the method for solving the problem of constructing a classification of objects of the same type with different types of variables**.**

Let *R* be the set of all real numbers.

We discredit the attribute space R^N, using the approach proposed in [4], and to characterize the proximity of similarity of vectors R^N we introduce the following evaluations.

We introduce *N* - dimensional vector of weights of variables

$$\overline{w} = \overline{w}(\overline{w}_1, \overline{w}_2, ..., \overline{w}_N),\ 0 \le \overline{w}_j \le 1,\ j = \overline{1,N},$$

so $\overline{w}_j$ - is weight of variable *j*.

Let s_p and s_q be two arbitrary points from space R^N. Based on fairly general considerations for the measure of proximity of these two points on *j* - coordinate it's convenient to take some function of the modulus of the difference in the values of this objects' coordinate s_p и s_q:

$$r_j(p,q) = w_j \times f(|t_{pj} - t_{qj}|),$$

where t_{pj} and t_{pj} - j point coordinates s_p and s_q.

We define this object distance function s_p to object s_q on coordinate j.

Following the description of the estimation calculation algorithms, we introduce a numerical N - dimensional vector

$$\bar{\varepsilon} = \bar{\varepsilon}(\varepsilon_1, \varepsilon_2, ..., \varepsilon_N)$$

- vector of threshold estimates by attributes, we explicitly define the distance function of the s_p and object s_q using the following condition

$$r_j(p,q) = \begin{cases} 0, \text{ если } [t_{pj} - t_{qj}] \succ \varepsilon_j \\ w_j, \text{если } [t_{pj} - t_{qj}] \le \varepsilon_j \end{cases}$$

Distance R (p, q) between points s_p and s_q we now define as follows:

$$R(p,q) = \frac{1}{N}\sum_{j=1}^{N} r_j(p,q)$$

Which implies that for any s_p и $s_q \in R^N$ there is an inequality

$$0 \le R(p,q) \le 1.$$

Let us consider the implementation of the trajectory classification method, which is further used by the software module to solve the trajectory classification problem.

Having replaced the objects with descriptions in the form of coordinates by time trajectories, we consider the construction of the question of constructing a classification of trajectories at a given time interval.

Let there be a multitude K^{tr} trajectory at a given time interval.

The idea of the method to construct the desired classification. The threshold value of the distance between the trajectories is set. Then a graph is constructed, the vertices of which are all given trajectories, the vertices are connected by edges, the distances between which do not exceed the threshold value. At a certain threshold value, the graph is divided into separate classes.

Let us consider the implementation of the method for solving the problem of classification of trajectories.

1. The choice of a certain value of ρ as a threshold distance for assessing the proximity of the trajectories to each other;
2. Fixing an arbitrary trajectory $T_r \in K^{тр}$, where $K^{тр}$ – is initially given set of classified trajectories;
3. Find all trajectories that are no more than ρ from the selected trajectory Tr. We get a subset of the trajectories. Let us call it a class K_1.
4. Then, in turn, for each of the trajectories included in the class K_1 with root T_1, using the same rule, we will find neighboring trajectories, we receive the completion of the class K_1.
5. The procedure continues until such a subset of the trajectories K^{tr} is distinguished that none of the trajectories of the class K^1 has close to $K^{tr} \setminus K^1$ trajectories.
6. We accept the formed set of trajectories as a class K_1.
7. We fix a new trajectory from $K^{tr} \setminus K^1$ and in the same way we form a class of trajectories K^2
8. We take the generated set of trajectories as the class of trajectories K^2.
9. We fix a new trajectory from $K^{tr} \setminus K^1 \setminus K^2$ and in the same way we form a class of trajectories K^3, etc.
10. Let q classes of trajectories K^1, K^2, ..., K^q be found. If the combination of the selected classes coincided with the original set of K^{tr} trajectories, then the classification process is completed, otherwise a new class $K_q + 1$ is constructed from the trajectories of the $K^{tr} \setminus K^1 \setminus K^2 ... \setminus K_q$

The resulting classification of the trajectories is declared as required.

The above approach allows setting the classification problem for completely arbitrary objects, the descriptions of which contain signs of a mixed type - quantitative and qualitative.

The proposed classification algorithm can work with information along trajectories represented by heterogeneous signs - of a quality and discrete type.

Conclusions. The proposed approach has established the principal possibility to use the proposed methodology to solve the problem of dividing given trajectories represented by time series into classes. It allows obtaining a model that, according to formal rules, determines the classification of trajectories by sets of heterogeneous features of its state at certain points in time and improves the reliability of determining the classification.

This research was financially supported by the Ministry of Education and Science of the Republic of Kazakhstan and was carried out within the framework of the scientific project, which is being implemented at the Institute of Information and Computer Technologies.

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ТОЛТЫРЫМ МАТЕРИАЛЫНЫҢ ҚАТАЮ КЛАССИФИКАЦИЯСЫН АНЫҚТАЙТЫН МОДЕЛЬ

Аннотация. Пайдалы қазбалардың бірқатар кен орнын игеру барысында қолданылатын толтырым материал күйінің класын анықтау маңызды және өзекті ғылыми-техникалық мәселе болып саналады, толтырымның оперативті дайындығын анықтау үшін химиялық-технологиялық қатаюдың үдеріс күйін талдау әдістері мен тәсілдерін әзірлеу қажеттілігі туды. Жұмыста материал күйінің алдыңғы даму үдерістері туралы ақпарат болған жағдайда толтырым материал күйінің даму траекториясының классификациясын анықтау мәселесін шешудің әдістемесі берілген.

Ұсынылған әдістеме басқарудың автоматтандырылған жүйесіне жатады және технологиялық үдерісті дискретті уақытша қарауға жол беретін күрделі объектілерді басқаруда пайдаланылуы мүмкін. Әдістеме құру үшін осы объект, жағдай, көпөлшемді динамикалық (уақытша) қатарда ұсынылатын үдерістерді тану және жіктеу әдістері қолданылды. Көппараметрлі динамикалық (уақытша) қатар ретінде қарастыруға болатын толтырым материалының қатаю үдерісін химия-технологиялық процесс ретінде қарастыру әр уақытта бетбелгінің жай-күйін жіктеу негізінде толтырым материал күйінің даму класын анықтауға мүмкіндік береді. Үдеріс күйі даму процесі траекторияларының класы туралы априорлық ақпарат болмаған жағдайда бірнеше пайдалы қазба кен орындарын игеруде қолданылатын толтырым материалдарының жай-күйін дамыту траекториясын жіктеу міндетін формалау ұсынылған. Проблеманы формалау негізінде үдерістердің даму күйінің бұрынғы үдеріс траекторияларының белгісі туралы қолда бар ақпарат бойынша бетбелгі материалы жай-күйінің даму траекторияларын жіктеуді анықтау міндетін шешу әдістемесінің сипаттамасы келтірілген.

Мақалада толтырым материалының жұмысқа дайындығын анықтаудың бұрынғы әдістері келтірілген. Олардың артықшылықтары мен кемшіліктері көрсетілген. Қазіргі әдістердің негізгі кемшілігі – құбылысты толық көрсетпейтін қатаю үдерісінің жеке сипаттау белгілерінің біржақтылығы. Ұсынылған тәсіл көпөлшемді уақыт қатары берілген траекторияларды класқа бөлу мәселесін шешудің жолдарын көрсетеді. Әдістемені қолданудың принципті мүмкіндігін белгілейді, бұл формальды ережелер бойынша оның жай-күйінің түрлі белгілерінің жиынтығы бойынша траекториялардың жіктелуін белгілі бір уақыт мезеті бойынша анықтайды және жіктеуді дұрыс анықтауға мүмкіндік береді.

Көпөлшемді динамикалық (уақытша) қатар түрінде ұсынылған технологиялық үдерісті дискретті қарауға мүмкіндік беретін көптеген күрделі үдерістер үшін қолдану мүмкіндігіне негізделген әдістеменің қамтылу аясының кеңдігін атап өткен жөн. Ұсынылған әдіс қоспа жағдайын бағалау процесін оңтайландырады, дәлдікті арттырады. Тапсырманы шешу әдістемесі бір-бірінен алыс білім салаларында кеңірек қолданыс табады. Жұмыс нәтижелері қоспаны бақылаудың дәстүрлі әдістері бойынша бірқатар артықшылыққа ие және басқа білім саласының өкілдері үшін қызықты.

Түйін сөздер: болжам, бетбелгі материалы, қауіпсіздік, динамикалық (уақытша) қатар, бейнені тану.

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МОДЕЛЬ ОПРЕДЕЛЕНИЯ КЛАССИФИКАЦИИ ПРОЦЕССОВ ТВЕРДЕНИЯ ЗАКЛАДОЧНОГО МАТЕРИАЛА

Аннотация. Определение класса состояний закладочного материала, применяемого при разработке ряда месторождений полезных ископаемых, является важной и актуальной научно-технической проблемой, что вызвало потребность в построении способов и методов анализа состояний химико-технологического процесса твердения для определения эксплуатационной готовности закладки. В данной работе представлена методика решения задачи определения классификации траекторий развития состояний закладочного материала при наличии информации о прошедших ранее процессах развития состояний материала.

Предложенная методика относится к автоматизированным системам управления и может быть использована при управлении сложными объектами, допускающих дискретно временное рассмотрение технологического процесса. Для построения методики были использованы методы распознавания и классификации данных объектов, ситуаций, процессов, представляемых многомерными динамическими (временными) рядами. Рассмотрение процесса твердения закладочного материала как химико-технологического процесса, который можно рассматривать как многопараметрический динамический (временной) ряд позволяет определить класс развития состояния закладочного материала на основе классификации состояния закладки в каждый момент времени. В работе предложена формализация задачи классификации траекторий развития состояний закладочных материалов, применяемых при разработке ряда месторождений полезных ископаемых, при отсутствии априорной информации о классах траекторий уже прошедших процессов развития состояний процессов. На основе проведенной формализации проблемы приведено описание методики решения задачи определения классификации траекторий развития состояний закладочного материала по имеющейся информации о признаках траекторий уже прошедших процессов развития состояний процессов. В статье приведены ранее предложенные методы определения момента эксплуатационной готовности закладочного материала. Показаны их преимущества и недостатки. Основным недостатком существующих методов является односторонность признаков описания процесса твердения в отдельности, что не отражает полную картину происходящего явления и является недопустимым.

Предлагаемый подход установил принципиальную возможность применения предлагаемой методики для решения задачи разбиения заданных траекторий, представленных многомерными временными рядами, на классы, что позволяет получить модель, которая по формальным правилам определяет классификацию траекторий по наборам разнотипных признаков его состояния в определенные моменты времени и позволяет повысить достоверность определения классификации. Хочется отметить широту охвата методики, которая заключается в возможности ее применения для большого множества сложных процессов, позволяющих дискретное рассмотрение технологического процесса, представленных в виде многомерных динамических (временных) рядов. Предложенный способ оптимизирует процесс получения оценки состояния смеси, повышает точность.

Методика решения задачи может найти обширную область применения в достаточно далеких друг от друга областях знаний. Результаты работы имеют ряд преимуществ перед традиционными методами контроля и интересны для других областей знаний.

Ключевые слова: прогноз, закладочный материал, безопасность, динамические (временные) ряды, распознавание образов.

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