Bases of intelligent system construction of the pipeline technical condition diagnostics

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Abstract. The urgent of creating the intelligent systems for revealing different kinds of regularities and decision-making in the problem area of pipeline technical condition diagnostics is considered. The technical condition diagnostics of pipeline is strongly dependent on the pipeline parameters, hydrodynamic characteristics of the pipeline-transported substance and that of environment (ambient medium). The advisability for the construction of the intelligent system for the pipeline technical condition diagnostics (IS PTCD) based on intelligent instrumental software (IIS) IMSLOG ambient medium, aimed at revealing different types of regularities in data and knowledge, decision-making and its justification with using cognitive tools, is shown. The matrix way of data and knowledge representation in the problem area and the main stages of IS PTCD constructing based on IIS IMSLOG IS PTCD are given. This will allow to reveal different types of regularities in data and knowledge on the base of the features that influence on the technical condition of the pipeline and, as well as make-decisions of the diagnostic and repair- prophylactic character. IS PTCD is essentially useful for the engineers in the problem area of pipeline-transported substance for decision-making and its justification with using cognitive tools, as well as for research activities and also for student training programs in the problem area.

1. Introduction

The urgent of creating the intelligent decision-making systems for different interdisciplinary areas is beyond doubt. D.A. Pospelov [1] greatly contributed to the development of mathematical foundations of intelligent systems structure. Separate directions of the intelligent systems' theory are considered in [1]: knowledge representation, inference on knowledge, languages of communication, text understanding, training models, action planning and visual information processing. In the publication [2] YuryZhuravlev proposed test methods for pattern recognition and justified the reasonable of their use in intelligent systems. the mathematical methods based pattern recognition and their implementation in software systems are presented in [3]. The diagnostic tests (unconditional, conditional, mixed) and cognitive graphics tools in intelligent systems are given in [4]. The intelligent instrumental software (IIS) IMSLOG has been created to constriction the applied intelligent systems based on the pattern recognition test methods [4] is presented in [5]. Construction of the intelligent biomedical systems on the base of IIS IMSLOG [4] are described in [6]. Construction of the hybrid intelligent systems of information security attackers based on the synergy of several sciences and scientific directions is given in [7]. The mathematical apparatus is based on a combination of test pattern recognition methods implemented in IIS IMSLOG and fuzzy logic. Various approaches to the medical intelligent systems creation are presented in [8,9]. The intelligent systems for medical data analyzing based on the DSM method application are presented in [10]. The intelligent systems in education and their application are described in [11]. The intelligent systems based on reliable and probable inference are described in [12]. In this paper we present just a few publications [1-12], devoted to the development and application of intelligent decision-making systems.

Another obviously urgent problem is application of modern computer systems in the oil and gas industry to improve quality of services during the hydrocarbons transportation process [13,14].

The intelligent system for the pipeline technical condition diagnostics (IS PTCD) development is a key innovative project of oil and gas companies to ensure reliability and safety during the process of oil and oil products transportation [15]. The correctly chosen method of the technical condition diagnostics, accurate determination of the residual resource, reasonable making the schedule at the pipeline, as well as formation of premature failures forecasts exclude a great number of problems, such as incidents, accidents, the process of hydrocarbons transportation shutdowns and nuisance financial costs [16-22]. The publications [16-22] contain national standards [16], federal laws and norms [17-21, 22].

Due to a large number of parameters influencing any pipeline technical condition it is necessary to use up-to-date computer systems.

The problems of intelligent systems using based on principles of artificial neural networks [23], Bayesian networks [24], evidence theory or Dempster-Shafer theory [25] and expert systems [26] do not consider the problem of the pipeline technical condition determining.

We suggest constructing the intelligent systems those are based on the pattern recognition test methods. To compare with other methods mentioned in the papers [23-26] for example, these ones have the following advantages: they allow taking into account the information which is in the values of features combinations. They do not require strong assumptions about the properties of the object under study; they allow solving the problem of recognition in the presence of a relatively small training sample for each pattern in the large feature space and with a large number of patterns [2, 4].

The technical condition of a pipeline is influenced by great number of characteristic features (parameters). The urgent of applying up-to-date computer systems in order to solve two key problems as revealing different kinds of regularities within pipeline parameters, and decision-making pipeline technical condition diagnostics.

It is advisable to create an intelligent system for the pipeline technical condition diagnostics intended to reveal different kinds of regularities, decision-making and justification based on cognitive graphic tools usage. Creation of such intelligent system is proposed to be carried out on the basis of IIS IMSLOG [5].

The test methods of pattern recognition are suggested for decision-making and its justification to choose a method of technical condition diagnostics and create IS PTCD on their basis. For IS PTCD construction it is advisable to use the available programs, implemented in the laboratory of intelligent systems (LIS) of the Tomsk state University of Architecture and Building (Tomsk, Russia) supervised by Prof. Anna Yankovskaya. The researchers have developed three original intelligent instrumental software (IIS) for constructing applied intelligent systems. More than 30 intelligent systems are based on them. These systems are intended for different areas, such as electronics, education, geology, psychology, road zoning, medicine, medical emergencies, ecology, eco-biomedicine and others [4-6, 12, 27, 28].

In this paper we consider the description of a matrix model of data and knowledge representation in the intelligent system for technical condition diagnostics. Then, discuss structuring attribute space providing safety in the process of hydrocarbons transportation; an example representing a fragment of the matrix describing the data and knowledge representation for pipelines technical condition diagnostics. Finally, there is a brief description of the mathematical foundations of the IS PTCD structuring and its design based on (IIS) IMSLOG.

2. Matrix model of data and knowledge representation in the intelligent system of pipeline technical condition diagnostics

The IS PTCD having been constructed on the basis of (IIS) IMSLOG [5] is based on the matrix model of data and knowledge representation according to the learning sample. This sample sets the objects description, with objects belonging to the known and includes an integer description matrix **Q**, the diagnostic type of distinguishing matrix $\mathbf{R_1}$, single-column patterns matrix **R'** and the organizational and management type of distinguishing matrix $\mathbf{R_2}$

Description matrix **Q** defines objects descriptions in the characteristic features space. The rows of **Q** are mapped to the training objects those correspond to the pipeline condition; the columns are mapped to characteristic parameters (features (CF) those specify various parameters influencing the pipeline condition. A row of **Q** is a combination of the CF values describing the parameters of the pipeline, hydrodynamics of the substance transported in it, as well as hydrological, aerological and atmospheric influences on the pipeline. The element q_{ij} of **Q** specifies the value of *j-th* CF for *i-th* object. For each attribute z_j ($j \in \{1,2,..., m\}$) either its partitioning intervals changing or an integer value are specified. If the value of a feature is not essential for the object, it is marked with a dash (" – ") in the respective element of **Q**.

The rows of the $\mathbf{R_1}$ are compared to the same rows of **Q**, and the columns are compared to the characteristic features (CF), which divide the training objects into equivalence classes, and each subsequent column divides the previous one into equivalence classes. $\mathbf{R_1}$ is intended for pipeline technical condition diagnostics, as well as for revealing type and class of defect [4]. CFs take integer values and are marked with a symbol " – " (dash), that means no defect.

It should be noted that proposed model allows us to represent not only data but also experts' knowledge, because one row of **Q** describes subset of the similar objects in the form of an interval (using a dash "–"). All these objects have the same final solution set by the corresponding row from $\mathbf{R_1}$.

The set of all non-repeating rows of the $\mathbf{R_1}$ is compared to the set of selected patterns, those are presented as **R'**, and its elements are the numbers of patterns.

The organizational and management type of $\mathbf{R_2}$ is designed to determine the sequence of repair-prophylactic activities on the pipeline (DSRPAP) [5].

The rows of $\mathbf{R_2}$ are mapped to the rows of the **Q** and $\mathbf{R_1}$ and the columns are mapped to the classification features that divide the training objects into equivalence classes. Similarly, as for $\mathbf{R_1}$, CF take integer values, or they are marked with "–" (dash).

The data and knowledge structuring for the linear part of the pipeline technical condition is carried out according to the above-mentioned matrix model of data and knowledge representation.

The rows of **Q** are mapped to the parameters of the pipeline, hydrodynamics of the substance transported in it as well as hydrological, aerological and atmospheric influences and represent only a part of the various combinations of CP values.

To form the characteristic and classification parameter space some references have been used, including national standards [17-22, 29-34]. The real parameters given by us to integer ones, as well as the integer parameters are recoded to integer ones if their number is large (more than 30). CFs those are listed below can be represented by their partitioning intervals.

Let us note that the list of CFs and their partitioning intervals listed in Table 1 represent only a part of different combinations of CF values.

Table 1. Characteristic features and their partitioning intervals.

Characteristic feature		Intervals
Pipeline laying type	z_1	1 – underground; 2 – surface; 3 – suspended; 4 – aboveground; 5 – underwater.
Section area (m^2)	z_2	1 – to 0,3 inclusive; 2 – from 0,3 to 0,5; 3 – from 0.5 to 0.7; 4 – from 0,7 to 0,9; 5 – from 1 to 1.2; 6 – from 1,2 to 1,4;
Pressure (MPa)	z_3	1 – from 0,25 to 0,75; 2 – from 0.75 to 2.5; 3 – from 2,5 to 5; 4 – from 5 to 6,4.
Service life (years)	z_4	1 – to 1; 2 – from 1 to 3; 3 – from 3 to 5; 4 – from 5 to 10; 5 – from 10 to 20; 6 – from 20 to 30.
Temperature (°C)	z_5	1 – from 0 to 10; 2 – from 10 to 20; 3 – from 10 to 20; 4 – from 20 to 30; 5 – from 30 to 40; 6 – from 40 to 50; 7 – from 50 to 60; 8– from 60 to 70; 9 – from 70 to 80; 10 – from 80 to 90; 11 – from 90 to 100;
Density (kg/m^3)	z_6	1 – from 550 to 580; 2 – from 580 to 610; 3 – from 610 to 640; 4 – from 640 to 670; 5 – from 670 to 700; 6 – from 700 to 730; 7 – from 730 to 760; 8 – from 760 to 790; 9 – from 790 to 820; 10 – from 820 to 850; 11 – from 850 to 880; 12 – from 880 to 910; 13 – from 910 to 940; 14 – from 940 to 970; 15 – from 970 to 1000;
Type of the fluid	z_7	1 –water; 2 – condensate; 3 – oil; 4 – ether; 5 – spirit; 6 – gasoline; 7 – kerosene; 8 – gas;
Element of a hydraulic pipe	z_8	1 – tee; 2 – pipe; 3 – elliptical plug; 4 – bend; 5 – stop valves; 6 – incut; 7 – loating; 8 – weld seam;
Climatic region	z_9	1 – IA; 2 – IB; 3 – IC; 4 – ID; 5 – IE; 6 – IIA; 7 – IIB; 8 – IIC; 9 – IID; 10 – IIIA; 11 – IIIB; 12 – IIIC; 13 – IVA; 14 – IVB; 15 – IVC; 16 – IVD

The classification features (CF) and their values are given in tables 2 and 3 for $\mathbf{R}_1$ and $\mathbf{R}_2$ matrices.

Table 2. List of classification features and their values for $\mathbf{R_1}$ matrix**.**

Classification feature		**Values**
Defect type	k_1	1 – certain type on the part of a section; 2 – combined defects; 3 – certain type at welds; 4 – defect on the sections with 2 or more repair structures;
Defect classification	k_2	1 – defects of geometry; 2 – defects of a pipe wall; 3 – defects of a weld; 4 – inadmissible connecting details; 5 – inadmissible constructive details and welded elements

Table 3. List of classification features and their values for $\mathbf{R_2}$ matrix.

Classification feature		**Values**
Diagnostic method	k_1	1 – visual and measuring; 2 – ultrasonic inspection (a method of the directed waves); 3 – ultrasonic thickness measurement; 4 – ultrasonic inspection of welded joints; 5 – eddy current pipe inspection; 6 – magnetic powder; 7 – capillary inspection; 8 – magnetometric;
Method of repair	k_2	1 – grinding; 2 – welding; 3 – installation of a repair design; 4 – defect cutting; 5 – replacement of a section;

$$
\begin{array}{c}
\quad z_1\; z_2\; z_3\; z_4\; z_5\; z_6\; z_7\; z_8\; z_9 \\
Q = \left|\begin{array}{ccccccccc}
2&3&2&5&6&1&3&8&5\\
2&3&2&5&5&9&2&2&5\\
2&2&2&4&6&1&3&8&5\\
3&3&2&6&6&1&3&8&5\\
2&3&2&6&6&1&3&4&1\\
2&2&2&5&5&9&3&8&5\\
2&2&2&6&5&9&8&1&5\\
1&3&2&5&4&6&8&1&5\\
1&3&1&5&4&5&8&1&2\\
2&3&1&6&5&5&3&8&5\\
1&2&1&5&6&1&3&1&5\\
2&2&2&4&6&1&3&8&5\\
2&3&3&1&6&5&1&2&6\\
3&2&2&1&5&5&5&2&8\\
2&3&2&1&4&5&5&8&5
\end{array}\right|
\end{array}
\quad
\begin{array}{c}
k_1\; k_2 \\
R_1 = \left|\begin{array}{cc}
1&5\\ 1&3\\ 1&3\\ 1&2\\ 4&-\\ 4&-\\ 4&-\\ 1&5\\ -&-\\ -&-\\ 1&2\\ 1&2\\ 1&3\\ -&-\\ 1&2
\end{array}\right|
\end{array}
\quad
R' = \left|\begin{array}{c}
3\\2\\2\\4\\1\\1\\1\\3\\6\\6\\4\\4\\2\\6\\4
\end{array}\right|
\quad
\begin{array}{c}
k_1\; k_2 \\
R_2 = \left|\begin{array}{cc}
1&4\\ 6&-\\ 6&-\\ 3&2\\ -&5\\ -&5\\ -&5\\ 1&4\\ -&-\\ -&-\\ 3&2\\ 3&2\\ 6&-\\ -&-\\ 3&2
\end{array}\right|
\end{array}
\begin{array}{c}
\\ 1\\2\\3\\4\\5\\6\\7\\8\\9\\10\\11\\12\\13\\14\\15
\end{array}
$$

Figure 1. Fragment of the description matrix **Q** and distinguishing matrices $\mathbf{R_1}$, **R'** and $\mathbf{R_2}$.

Figure 1 is an illustrating example of data and knowledge representation according to the pipeline technical condition diagnostics. This example is a fragment of data and knowledge description matrix in oil and oil products transportation process.

The given description matrix in figure 1 consists of nine columns compared to the above CFs and fifteen rows.

The rows of $\mathbf{R_1}$ matrix are associated with the rows of **Q** matrix, the columns are associated with the aforementioned CF k_j ($j \in \{1,2\}$). The $r_{i,j}$ element of the distinguishing matrix shows the belonging of the i-th object (pipeline condition) to a class based on the j-th classification mechanism (type and class defect) by way of indicated the class number. For the problem under study ensuring safety at hydrocarbons transportation the row of $\mathbf{R_1}$ specifies the type and class of a pipeline defect.

As mentioned above, the set of all non-repeating rows of $\mathbf{R_1}$ is associated with the set of selected patterns represented by the **R'**, those elements are numbers of the patterns. This model does not permit intersecting objects from different patterns. Presence of such intersections is revealed via analysis using IS PTCD.

The rows of $\mathbf{R_2}$ are compared to the corresponding rows of **Q** and $\mathbf{R_1}$ matrices, and the columns are compared to the above classification features. A row of $\mathbf{R_2}$ specifies the method of diagnostics and repair.

Since the limits of the paper publication do not allow us to fully present the matrix description of data and knowledge, just a fragment of matrix data and knowledge on the pipeline technical condition diagnostics is shown in Figure 1 (matrix **Q**, $\mathbf{R_1}$, **R'**, $\mathbf{R_2}$). The aforementioned fragment, being a partial description of knowledge, since only a part of the characteristic feature space and its values of CPs is used to determine pipeline diagnostics, contains 9 columns and 15 rows in Q, and 2 columns in each of $\mathbf{R_1}$ and $\mathbf{R_2}$ matrices.

3. Brief description of the mathematical foundations of IS PTCD constructing

Since the limits of the paper do not allow us to provide a description of the mathematical foundations of IS PTCD constructing, and the mathematical apparatus for constructing a large number of applied intelligent systems has been presented in a number of publications [4-6, 12, 27, 28], let us talk of them briefly.

One of the important tools of the data and knowledge analysis [4] are diagnostic tests, i.e. tests distinguishing objects from different patterns [4], constructed during of the regularities revealing in the data and knowledge base which are represented by **Q**, $\mathbf{R_1}$, $\mathbf{R_2}$ matrices. These tests are used for decision - making based on the methods test pattern recognition.

The regularities in knowledge are subsets of features, such as: constant; stable (constant inside a pattern); non–informative (not distinguishing any pair of objects); alternative (in the sense of their inclusion in DT); dependent (in the sense of the inclusion of subsets of distinguishable pairs of objects); unessential (not included in any irredundant unconditional diagnostic test-IUDT); obligatory (included in all IUDT); pseudo-obligatory (which are not obligatory, but included in all IUDT involved in decision-making) features; as well as all minimal and all (or part, for a large feature space) irredundant distinguishing subsets of features that are essentially minimal and irredundant DTs, respectively; mixed DT (MDT), which are the optimal combination of unconditional and conditional components.

The regularities include fault-tolerant IUDT (FT IUDT) – stable to errors of measurement (entry) of the object under study description, then fault-tolerant MDT (FT MDT) – stable to errors of measurement (entry) of the object description, and finally, IUDT, as well as FT IUDT are characterized by the simultaneous presentation of all its constituent features of the object under study in decision-making.

Among the regularities of the pipeline technical condition are the aforementioned regularities, which will be used for decision-making and justification. The revealed regularities will significantly reduce number of measurements to determine the technical condition of the pipeline.

4. Designing IS PTCD based on (IIS) IMSLOG

In detail IIS IMSLOG is described in [5]. There are 4 stages of IS PTCD constructing based on (IIS) IMSLOG [5] stages:

1) Data and knowledge systematization and structuring on pipelines technical condition diagnostics. To achieve this goal, it is necessary to work with the experts in the problem area revealing the most informative data and knowledge, forming description of the training sample objects and ensuring safety of hydrocarbons transportation. The functional structure of IS PTCD is determined. The specialists on IS PTCD designing define the architecture and predicates suitable for revealing patterns in knowledge and decision-making.

2) Layout of the required configuration of the intelligent system. The layout is carried out by connecting the kernel of (IIS) IMSLOG and appropriate software modules.

3) Creation of knowledge base module using the management tools of the knowledge module. Formation of the module structure and description of the objects forming the training sample.

The system under description allows to convert information from other software systems. The knowledge module is processed by tools of the knowledge base analysis and optimization module in order to reveal the regularities, according to those a set of decision rules is formed. This set will be used by the decision-making module to analyze the objects under study describing the condition of the pipeline. As soon as a set of decision rules is formed, the knowledge base will be transformed into a special format to accelerate access to knowledge with context the information security requirements.

4) Final adjustment of the constructed IS PTCD in order to transfer to a customer. The internal links are established, the dictionaries responsible for the dialogue with an user are registered.

5. Conclusion

In this paper for the first time we propose the creation of intelligent system for the technical condition of the pipeline diagnostics and determining the sequence of repair and preventive measures in this problem area (IS PTCD). This system is designed to reveal different types of regularities within various parameters of the pipeline those influencing its technical condition. IS PTCD is also intended for decision-making and justification on technical condition of the pipeline diagnostics.

Application of the matrix model of data and knowledge representation in the problem area of reliability and safety during hydrocarbons transportation process is proposed for the first time as well. The original characteristic and classification feature space for the proposed matrix model has been formed.

The substitution, efficiency and prospects of the application of MDT, which is a new paradigm for the creation of IS PTCD, are connected with: 1) the possibility of sequential extraction of information about the object under study for the conditional component of the MDT; 2) the advantages of using unconditional tests when construction decision rules; 3) the advisability of using MDT when organizing an intelligent interface (constructing a questionnaire).

The advisability for the construction of the intelligent system IS PTCD based on intelligent instrumental software (IIS) IMSLOG [5] is justificated.

After further development, IS PTCD will allow to diagnose technical condition of the pipeline and to define effective measures due to diagnostics results quickly and at lower cost. A pipeline servicing company will be able to monitor the pipeline condition in real time and to respond promptly to any changes in it when making diagnostic, as well as to exclude possible emergencies.

IS PTCD can be used at oil and gas production enterprises, as well as for training specialists in the field of reliability and safety of pipeline transport.

In addition, it is advisable to use IS PTCD by companies operating waste water disposal organizations in different regions of the country (cities, towns, etc.).

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