System for determining the state of the object surface based on fuzzy output rules

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Abstract. The article provides information on hydrocarbon production in the Russian Federation, accidents at facilities supervised by Rostekhnadzor, and also presents a statistical analysis of the causes of accidents at high-risk facilities. Typical issues of studying the condition of the surface of an oil and gas object are considered on the basis of the electron-projection method that simulates the moiré effect and evaluates the surface topology by a system of fuzzy inference rules implemented in the structure of a neural network.

Keywords. System, analysis, decision-making algorithm, rules of fuzzy inference, moire method, structure of a neural network

1. Introduction

Improving the constructive safety of high-risk facilities (HRF) in the oil and gas field is one of the priority issues for the integrated safety of enterprises of the fuel and energy complex in the Russian Federation. This direction is acquiring particular relevance in connection with the largest environmental disaster that occurred in Norilsk in May 2020. The Russian Federation has been and remains one of the largest players in the hydrocarbon market. According to the Ministry of Energy of the Russian Federation, in 2019 Russia produced oil in the total volume of 560338.06 thousand tons, 737708.737 thousand tons of gas and 35731.185 thousand tons of gas condensate. The number of emergencies arising during the operation of HIFs in the field of oil and gas production remains a problem.

According to the Federal Service for Environmental, Technological and Nuclear Supervision (Rostekhnadzor), in 2019 a number of accidents occurred in the Russian Federation at the facilities supervised by Rostekhnadzor (see Table 1). Statistical data is shown at Fig. 1. The analysis of the information provided shows that almost a third of the accidents (about 36-39%) are accounted for by HRFs in the oil and gas sector. One of the main reasons for such a number of accidents is the deterioration of pipelines, tank farms and other facilities of the oil and gas complex. This assumption is also supported by an analysis of the causes of the spill of oil products that occurred in 2020. An incomplete list of accidents is:

- Fuel oil spill in the Primorsky Territory, Nakhodka on March 14, 2020. As a result of the explosion of the tank, over 2500 tons of fuel oil got into the environment. The explosion occurred due to wear and tear on the equipment.
Table 1. Accidents at the facilities supervised by Rostekhnadzor for 2019

| Supervision type                                                                 | Number of accidents |
|---------------------------------------------------------------------------------|---------------------|
| Supervision in the coal, mining, chemical, defense, metallurgical and other industries with the number of accidents 1-3 | 14                  |
| Pressure equipment supervision                                                    | 5                   |
| Supervision of objects of the main pipeline transport                            | 7                   |
| Supervision of oil and gas production facilities                                 | 8                   |
| Supervision of objects of the petrochemical and oil refining industry            | 19                  |
| Supervision of gas distribution and gas consumption facilities                   | 20                  |
| Supervision of electrical networks                                               | 24                  |
| Supervision of lifting structures                                               | 53                  |

Figure 1. Percentage of accidents at facilities supervised by Rostekhnadzor in 2019

- Spill in the Krasnoyarsk Territory. A tank with diesel fuel burst during its movement on a barge of Priangarskiy forestry across the Angara River.

Statistical analysis of the causes of accidents at oil transportation and storage facilities made it possible to conclude that the share of accidents caused by a group of defects associated with manufacturing and construction and installation works, on average, is 0.32; the share of accidents caused by corrosion processes is 0.28; the share of accidents caused by external factors is 0.31. External factors include the influence of man-made processes and accidental damage from third-party organizations, as well as the influence of ongoing physical and geological processes of a different nature.

At the same time, visual and measuring control is carried out at almost all stages of the life cycle of individual parts, assemblies and assemblies.
The peculiarities of diagnostics of specific objects are reflected in specialized documents: "Rules for construction and safe operation", as well as in various health standards. The government of the Russian Federation is taking various actions at the legislative level to ensure the safety of operation of hazardous facilities. In particular, the Federal Service for Environmental, Technological and Nuclear Supervision on December 15, 2020 approved the federal norms and rules in the field of industrial safety "Safety Rules in the Oil and Gas Industry", which came into force on January 01, 2021. These rules are aimed at preventing accidents and incidents at HRFs in oil and gas producing industries and at ensuring the readiness of organizations operating HRFs in oil and gas producing industries to localize and eliminate the consequences of accidents at HRFs. One of the points of the requirement for organizations operating HRFs is the requirement “… when using equipment in technological processes, including corrosion-resistant equipment, it is necessary to develop and apply protection measures against corrosion, wear and tear. …". To ensure the fulfillment of this requirement, as well as the requirements for the inspection of oil and gas facilities after major repairs, reconstruction, it is necessary to monitor objects subject to deformation and corrosion processes. This is an important prerequisite for improving the overall safety of the hazardous facilities. Assessment of the technical condition of the object under study determines its quality, identifies defects and damage, analyzes deformation processes and predicts their development. But the issue of remote monitoring of the state of objects using software and hardware systems remains relevant in the conditions of limited availability of objects for a human expert in many factors: remoteness, length, harmful environment, etc.

2. Results and discussion
At present, the issues of monitoring the technical condition of oil and gas industry facilities are still relevant. In this field, ultrasonic, electromagnetic, acoustic, optical and other methods of surface topology control are well known. Methods based on the use of the moiré effect [3, 4, 5] are promising and not fully investigated. When using them, a moiré pattern is formed when two ruled grids are overlaid. Such a picture can serve as a qualitative and quantitative characteristic for assessing the process of deformation of the surface of an object.

There is a known differential electron-projection method for measuring the shape of the surface of an object, the essence of which is to project a reference grid synthesized in a computer, which is an alternation of dark and light stripes, scanning this grid with a digital video camera, then comparing the received image with the synthesized grid and determining the surface parameters in each point [2, 6]. Moiré fringes (mechanical interference phenomenon) are possible in the following cases:

- Two grids of straight parallel lines with the same step $\alpha$ are overlaid, rotated relative to each other by an angle $\varphi$;
- Two grids are overlaid with different steps ($\alpha_1$ and $\alpha_2$) in the absence of rotation between them;
- Grids with different spacing and rotated relative to each other at an angle $\varphi$ are overlaid.

A promising area of research is the developed system for determining the surface topology using modern, more accurate non-contact methods and methods of intelligent information processing. The structural diagram of such a system is presented in [1, 2].

Figure 2 shows a generalized linear algorithm for the system for determining surface deformations. To build the surface topology and make a decision about the nature of deformations, it is necessary to perform three sequential stages of operations:

1. In the module synthesizing an object mesh on the surface of the studied object, parameters are set and the projected mesh is formed and projected onto the object using a block of laser emitters, the resulting object mesh is read by a digital camera and entered into the video memory of the processor module, where it is pre-processed. In case of a satisfactory image,
control is transferred to the next block. There is a generation of a picture of an imaginary raster in the processor module and a moiré pattern is obtained.

2. In the module generating moiré object, an imaginary raster is created and a moiré pattern is built, then the coordinates of the centers of the moiré stripes are determined, a matrix of heights is built for each local area of the surface of the object under study. The resulting array of parameters is transferred to the decision support system.

3. The Module for results processing and decision making is based on the accumulated knowledge and the new data obtained. The decision on the nature of the deformation of the object is made on the basis of an inference algorithm and fuzzy rules using a neural network.

The work [1] describes in detail the CBR technology, on which the decision-making block can be implemented. Another approach is based on fuzzy knowledge bases and fuzzy inference algorithms as part of fuzzy expert systems. As a tool for forming a knowledge base, it is proposed to use a neural network based on a fuzzy model [9-12].

To construct and study the surface of an object in conditions of uncertainty, it is necessary to take into account that the input variables can have clear and fuzzy values, each input condition has its own weight in the antecedent of the rule, and each fuzzy rule has its own degree of reliability. These requirements can be described by fuzzy rules of the form [7, 8]:

\[ \text{if } X \text{ then } Y \]  \hspace{1cm} (1)

where \( X = \bigcup_{i=1}^{n} x_i \) is the antecedent, i.e. the set of input parameters of the rule, \( Y \) is the consequent, i.e. the set of clear output values of the rule \( Y = (y_1, y_2, \ldots, y_m) \) with certainty \( D=\{0,1\} \).

Each input variable of the rule will depend on a clear or fuzzy input value and have its own weight:

\[ x_i = F_i^w(w_i) \]  \hspace{1cm} (2)
where $w_i$ is the weight of the conditional part of the rule, $w_i \in [0, 1]$.

$$F_i^* = \{F_i, \tilde{F_i}\},$$

where $\mu_{F_i(x_i)}$ is a membership function.

The research problem is reduced to the fact that the required fixed vector of input variables $X = (x_1, x_2, ..., x_n)$ is associated with a specific solution $y_i$.

The generalized scheme of the algorithm for assessing the state of the object's surface is shown in Figure 3 [13, 14, 15]. Algorithm for assessing the state of the surface of an object based on fuzzy rules:

1. Determination of the degree of triggering of the antecedent in the rule $E \in [0, 1]$:

$$E = \min \left( \mu_{\tilde{F_i}}(x_i^*) \right),$$

where $x_i^*, i = 1, n$ represents clear values of $n$ input variables of the rule, $\mu_{\tilde{F_i}(x_i)}$ represents the degree of membership of the values of the input variables to the fuzzy input values $\tilde{F_i}$.

2. Determination of the weight of the antecedent in the rule $V \in [0, 1]$:

$$V = \frac{\sum_{j=1}^{n} w_j}{\sum_{i=1}^{n} w_i},$$

where $w_i, i = 1, n$ – the weights of all constraints $\tilde{F_i}$ on the variables in the rule, $w_j, j = 1, n_1$ – constraint weights $\tilde{F_i}$ with known values.

Estimation of the accuracy of the proposed solution $C \in [0, 1]$:

$$C = E \times V \times D.$$

**Figure 3.** Algorithm for assessing the state of the object's surface

This algorithm is the basis for an inference algorithm based on fuzzy rules of the form (1) for assessing the surface topology of the object under study. Let us consider this algorithm in more detail (see Fig. 4).
Figure 4. Fuzzy rule-based inference algorithm

The algorithm starts by entering all clear values of the variables in the rules. For each rule of fuzzy inference, $E$ is calculated - the degree of triggering of the value of the input variable according to rule (5). If the value of $E$ is not equal to zero, then a set of problematic rules of fuzzy inference is formed, for which $V$ will be calculated - the weight of the antecedents by formula (6) and the accuracy of the solution $C$ by formula (7) for each rule will be determined. As a result of executing this algorithm, the only correct rule with the maximum accuracy estimate is selected, the output value of which corresponds to the real state of the surface of the object under study.

It is advisable to implement the presented algorithm in the form of a model underlying the training of a neural network (see Fig. 5).

Figure 5. The structure of a multilayer neural network
The first layer contains the variables of the fuzzy inference rules, the second layer simulates the input conditions of the fuzzy input variables in the rules. The result of the work of the second layer of the neural network is the values of the membership function. In the third layer, the degree of triggering of the antecedents is determined. In the next, fourth, layer of the neural network, the accuracy of each output value presented on the fifth layer is estimated. In the last layer of the neural network, the only correct solution is presented.

3. Conclusion

The described fuzzy model and the diagram of the presented neural network can be implemented in the form of a software package for making a decision on surface deformation. The implementation of the block for making a decision on the nature of the deformation on the neural network will allow in the future to exclude the participation of an expert in assessing the state of the object, thereby reducing the subjective nature of the assessment.

4. References

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