Case-based reasoning approach for monitoring multi-phase liquid in pipeline

O N Kuzyakov¹, I N Glukhikh², A E Sidorova¹ and M A Andreeva¹

¹ Industrial University of Tyumen, 38 Volodarskogo Str., Tyumen, Russia
² Tyumen State University, 6 Volodarskogo Str., Tyumen, Russia

E-mail: mayandr72@yandex.ru

Abstract. A method based on collecting, integrating and subsequence analyzing data on multi-phase liquid flow condition in pipeline is suggested in the paper. The principles of constructing multi-component liquid control system with the use of ultrasonic signal as a sensing one and initial execution algorithm of ultrasonic emitters-receivers with subsequent change of roles are presented as well. CBR method used while identifying multi-phase condition is an element of processing part of the system – intellectual decision-support system.

1. Introduction
A rapid development of oil industry involves highly automated technological processes for liquid hydrocarbons extraction and transportation. A range of relevant problems as providing safety, reliability and economical effectiveness at all levels of oil transporting system are solved by the means of complex automation.

Monitoring the transport system with decision-making on multi-phase liquid condition and oil pipeline condition considering all of its technological parameters is one of the most important issues of automated management. This monitoring involves real-time data collection and identification of liquid condition, recognition of flow regime in pipeline, assessment and prediction of the condition of technical object including detecting situations, which demand maintenance engineers, and dispatching staff involved.

Meanwhile, data collected may be undetermined, inaccurate, incomplete and unreliable because of dynamism and complexity of ongoing processes and heterogeneity of evolving multi-phase flow. Consequently, tasks of recognition multi-phase liquid flow regime and evaluating its influence on pipelines technical condition becomes challenging.

This fact is especially relevant for pipelines at mines, where multi-phase liquid flow regimes necessitate influence of corrosion on pipeline condition, and common technological solutions for monitoring and evaluating this condition are lacking nowadays.

The approach suggested in this paper for solving tasks mentioned is based on collecting and integrating data on multi-phase flow condition received in real-time mode and comparing them to samples (examples of flow regimes) known beforehand. A base of such samples is formed under laboratory conditions on the basis of multi-phase flow research on pipeline model and is supplemented by expert conclusions on each regime influence on pipeline technical condition.

2. Methods
2.1. Case-Based Reasoning
Case-based reasoning (CBR) [1-5], which is a decision-making method well-known in artificial intelligence sciences, became a methodological framework for implementation of such approach. The main idea of CBR is to use solution known from experience which proved to match such problems. In CBR-systems, pairs \(<\text{Situation (S)}, \text{Solution (R)}>\) make up cases kept in a specific case base (CB):

\[
\text{CB} = \{<S_k, R_k> | k = 1, 2, 3, \ldots, N\},
\]

where \(N\) is a number of cases in CB.

In case of problematic situation decision search in CBR-systems goes through the following stages: identification of current situation \(\text{Sit}\), search and selection of situation \(S^*\) in CB, which is the most similar to current \(\text{Sit}\), extraction of decision \(R^*\), which is in same CB as \(S^*\), estimation of the applicability degree and reuse of the decision found for current situation. If decision found in CB in this state is inapplicable to current situation it is adapted to new situation. Thus, CB replenishment is provided during system execution.

In general, a situation in CBR refers to a structured description of a certain state in system examined. The second component of case, a decision, may represent [4] a problem solving for the situation itself or its interpretive or both.

For search and selection of situation \(S^*\) in CB two main methods are used [4]: similarity search in parameter space and tree search. In the first instance, degree of similarity \(\rho (\text{Sit}, \text{Sit'})\) is entered and the task of searching is solved:

\[
S^* = \arg\min \rho (S, \text{Sit}).
\]  

(1)

In the second instance, with the use of decision tree a consistent classification of \(\text{Sit}\) is implemented by comparing \(\text{Sit}\) parameters values to restrictions set for decision tree nodes. In practice, a combination of both methods is presumably used when with the use of decision tree a subset of situations in CB is localized, and decisions are made in accordance to similarity degree.

CBR method is widely used in different subject areas: for identifying damages and forecasting mechanical systems conditions [6, 7], road traffic management [8], in software developing support systems [9], medical information systems [10-13], decision support in pipeline systems and other technological objects management [14-17], elaborating knowledge bases for geological and technological actions [18-19], etc.

In approach suggested for constructing multi-phase liquid monitoring systems in pipeline a current condition of multi-phase liquid flow in pipeline is accepted as \(\text{Sit}\). The samples-examples of flow regimes in pipeline represent a set of situations-examples \(S\) in CB and decisions \(R\) represent meta descriptions of key characteristics and features of regime, conclusions and forecast estimations on flow regime influence on pipeline state, recommendations for staff on actions in such situation (flow regime).

One of key problems in CBR monitoring system implementation is elaborating a way of formalization and a related way of identifying \(\text{Sit}\) parameters. Solution of these issues is represented hereafter.

2.2. Technical support of monitoring of multi-phase flow flowing regime in pipeline
System of identification multi-phase liquid flow regime in pipeline is suggested for collecting data on multi-phase flow parameters [20-22]. The system is presented at figure 1.

Ultrasonic signal is used in this system for determining multi-phase liquid flow parameters. The signal is registered by the receiver after it has come through the flow and its parameters are analyzed thereafter. Multi-phase liquid features affect signal extension which provides with opportunity to make necessary conclusions.
A concurrent scanning of all ultrasonic converter-receivers with one set emitter is performed by the system, then the emitter is reset, and scanning is performed again. Thus, in the process of system execution the role of each ultrasonic converter-receiver changes cyclically: in each loop of measurement only one of such elements serves as ultrasonic signal emitter while the others serve as receivers.

**Figure 1.** System structure

In figure 1 piezoelectric converters are used as ultrasonic emitters-receivers. Emitters-receivers $ER_1$ – $ER_n$ make up a group of converters which use ultrasonic fluctuation of set frequency to subsequently sense multi-phase liquid which flows perpendicularly to longitudinal axis of the pipe, and in each loop of measurement only one of converters serves as ultrasonic signal emitter while the others serve as receivers. That is why in each subsequent loop the following element serves as emitter, and the others serve as receivers. Emitters-receivers are located on the outside of pipe walls.

For more complex characterization of multi-phase liquid condition the pressure, temperature and flow velocity sensors are used inside the pipe. The microprocessor (CPU) which forms system run signal and gives a starting signal to the input of ultrasonic signal generator (USG), and ultrasonic multiplexer (UMS) manages execution of all elements of the system. UMS determines the sequencing of execution of converters (emitters-receivers), i.e. which one of them emits signal while the others receive it and transmits signal from USG to emitter chosen. At the same time CPU forms signal coming to timer-counter (T) which captures the time of forming ultrasonic signal and measures time of signal extension in the environment (multi-phase liquid in the pipe).

After ultrasonic signal has come from emitter through multi-phase liquid to the receivers, signals from outputs of receivers go to the inputs of analog memory block (AMB) and timer-counter (T), where the following parameters are captured: amplitudes of received signals which has come through solid environment and reflected from the interphase boundary, extension time of these signals and also
parameters from analog converters block representing current condition of the pipeline (pressure, temperature, flow velocity).

Therefore, the system described provides with continuous collection of data and estimation of values of parameters set, including amplitudes of received signals which has come through solid environment and reflected from the interphase boundary, \( \Sigma A_{ci} \); extension time of these signals into environment, \( \Sigma T_{ci} \); pressure inside the pipe, \( P_p \); flow velocity, \( V_f \).

Analog signals from AMB and T come to the input of analog multiplexer (AMS), and its output is connected to the input of analog-digital converter (ADC). Digital data from ADC comes to EPROM and is kept there. Information on precedents is also kept in EPROM. This data is used by intellectual decision-support system (IDSS) thereafter.

3. Results and discussions

Set of parameters and their values is the result of execution of system described. The parameters are used for formalized description of situations \( S \) and \( Sit \) with the use of vector in three-dimensional space, which is non-Euclidean in general case:

\[
(\Sigma A_{ci}, \Sigma T_{ci}, P_p, T_i, V_s).
\]  

Case in CB is

\[
CASE = <S, R, M>,
\]

where \( S \) is a vector in the parameter space described in equation (2); \( R = (R_1, R_2, R_3) \), \( R_1 \) is a meta description of multi-phase liquid flow regime matching \( S \); \( R_2 \) is conclusions and predicted estimations on flow regime influence on pipeline condition; \( R_3 \) is recommendations to maintenance engineers and dispatching staff (instructions, technological maps, guides etc.); \( M \) – references to other cases in CB associated with current case. The basic form of association is relation of cases to one class of regimes where classification is implemented on similarity of \( R \) decisions.

In this context, execution algorithm of system suggested consists of the following stages: system initialization; forming sensing signal with parameters set; identifying \( Sit \) – collecting data and creating situation description considering equation (2); choosing the most appropriate case \( CASE^* = < S^*, R^*, M^* > \) according to rule in equation (1); decision-making on possibility of direct application of \( R^* \) from this case or necessity of its adaptation.

For choosing the most appropriate case the following criteria are suggested:

\[
F = \sum_k \sum_i \alpha_{ki} f_i(Sit, S_k) \rightarrow \max \text{ with restriction } f_i(Sit, S_k) \geq 1 \text{ where } f_i(Sit, S_k) \in I_k,
\]

where \( f_i(Sit, S_k) = 1 \) under condition of equality of all \( i \)-th parameters in descriptions of situations \( Sit, S_k \) considering limitation of tolerable deviations of \( \sigma_i \) or \( f_i(Sit, S_k) = 0 \) if this condition is not met. \( I_k \) is a set of parameters on which the condition of equality of current situation to \( k \)-th sample is necessary; \( \alpha_{ki} \) is a weighting factor of relevance if \( i \)-th parameter in \( k \)-th sample of \( S_k \), \( \alpha_{ki} \in [0, 1] \) and \( \sum_i \alpha_{ki} = 1 \).

Thus, the threshold of \( F \geq 0.7 \) is used for decision-making on possibility of direct application of \( R^* \).

4. Conclusion

Decision-making on the precedent for building intellectual systems for monitoring multi-phase liquid flow in pipeline is suggested. Such systems may execute under conditions of uncertainty of data collected from the controlled object.

Decision-making on the precedent allows restoring current description of controlled object on the base of samples known, providing with complex characterization of multi-phase liquid and flowing regime in pipeline, suggesting other extra recommendations or actions.
References

[1] Montani S, Jain L C 2013 Successful Case-Based Reasoning Applications-2 (Springer) p 62
[2] Lenz M, Bartsch-Spörl B, Burkhard H-D 2003 Case-Based Reasoning Technology: From Foundations to Applications (Springer) p 405
[3] Watson I D, Marrir F 1994 Case-based reasoning: A review Knowl. Eng. Rev. 9 355–81
[4] Kolodner J L 1992 An introduction to case-based reasoning Artif. Intell. Rev. 6 3–34
[5] Aamodt A, Plaza E 1994 Case-based reasoning: foundational issues, methodological variations, and system approaches AI Communications, IOS Press 7 39–59
[6] Mujica L E, Vehi J, Rodellar J, Kolakowski P 2005 A hybrid approach of knowledge-based reasoning for structural assessment Smart Mater. Struct. 14 1554–62
[7] Olsson T, Funk P 2012 Case-based reasoning combined with statistics for diagnostics and prognosis JPCS
[8] Louati A, Elkosantini S, Darmoul S, Lamjed Ben Said 2016 A case-based reasoning system to control traffic at signalized intersections IFAC-PapersOnLine 49 149–54
[9] Rocha R G C, Azevedo R R, Sousa Y C, Tavares e de A and Meira S 2014 A case-based reasoning system to support the global software development Proc. KES2014 35 194–202
[10] López B, Pous C, Gay P, Pla A, Sanz J and Brunet J 2011 A framework for case-based medical diagnosis development and experimentation Artif. Intell. Med. 51 81–91
[11] Gómez-Vallejo H J, Uriel-Latorre B, Sande-Meijide M, Villamarín-Bello B, Pavón R, Fdez-Riverola F and Glez-Peña D 2016 Case-based reasoning system for aiding detection and classification of nosocomial infections Decis. Support Syst. 84 104–16
[12] Sreeparna Banerjee, Amrita Roy Chowdhury 2015 Case based reasoning in the detection of retinal abnormalities using decision trees Procedia Comput. Sci. 46 402–8
[13] Douali N A , De Roo J B and Jaulent M-C A 2012 Clinical diagnosis support system based on case based fuzzy cognitive maps and semantic web Proc. MIE 2012 180 295–9
[14] Bashlykov A A 2016 Pcedent theory methods application in decision-support systems in pipeline systems management Automation, telemechanization and communication is oil industry 1 23–32
[15] Varshavskiy P R, Eremeev A P 2009 Case-based reasoning in intellectual decision-support systems Artificial Intelligence and Reasoning 2 45–57
[16] Homem T P D, Perico D H, Santos P E, Bianchi R and Lopez de Mantaras R 2016 Qualitative case-based reasoning for humanoid robot soccer: A new retrieval and reuse algorithm Proc. ICCBR 2016 170–85
[17] Marzouk M M, Ahmed R M 2011 A case-based reasoning approach for estimating the costs of pump station projects JAR 2 289–95
[18] Gluhih I N, Piankov V N and Zabolotnov A R 2002 Situational models in corporate knowledge base on geological-technical measures' know-how Oil Industry 6 45–8
[19] Akhmadulin R K, Gluhih I N, Karyakin I Y 2016 An object-oriented model of case-based reasoning system using situations tree Proc. AICT 124–27
[20] Kuzyakov O N, Pindak A V 2007 Method of determination multi-phase flow regime in pipeline Patent RF 2311633
[21] Kuzyakov O N, Pindak A V 2006 Multi-phase flow control device in pipeline Patent RF 2198397
[22] Kuzyakov O N, Sidorova A E 2016 The system of monitoring of a multiphase mixture using the CRB-technologies Modern High Technologies 4 59-62