Data integrating approaches for oil pipelines maintenance

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Abstract. In this paper, we discuss how data integration can improve the quality of oil pipelines monitoring systems. We outline approaches that have been developing for collecting data from different type of sensors and describe steps of designing a Program Apparatus Complex (PAC). Various aspects of this problem are included: a brief overview of related works and existing monitoring systems and their development prospects; data integrating approaches; requirement analysis for computer-based data integration.

1 Introduction

Modern development and operation of the Russian oil pipeline network take place in subarctic environment that is characterized with sharp temperature fluctuations and unfavorable soils (wetlands, permafrost). It provokes internal and external corrosion, denting, buckling, object reorientation and deformation. In the course of time the number of exogenous processes increases. It makes necessary to install additional sensors and monitoring systems and formulates a plan for compensating activities in a form of diagnosis, repair and replacement of equipment.

At present there is a growing interest in data integrating platforms. Fig. 1 was obtained with semantic search in the Exactus Patent system based on semantic analysis of more than 64 thousand patents issued in the countries developing this problem (Great Britain, USA, Canada, Russia, Israel, Germany, etc.). Articles also confine attention to this aspect. The survey [1] shows usage of acoustic sensors and describes an active acoustic sensor network platform for pipeline monitoring and inspection. Authors [2] discusses how wireless sensor networks increase the spatial and temporal resolution of operational data from pipeline infrastructures. In [3] is described large critical infrastructure which requires 24/7 monitoring for safety and security. It involves integrated in situ and remote sensing together with large scale stationary sensor networks, that are supported by cross-border communication.

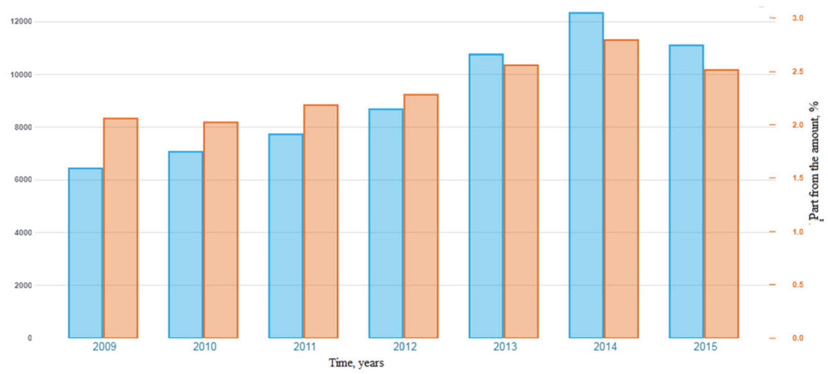

Fig. 1. Dynamics of patenting

It includes accelerometers, underground acoustic sensors; optical, thermal and hyperspectral video cameras or radar systems mounted on strategic areas. [4] leverages dynamic data from multiple information sources sensing data, geophysical data, human input, and simulation/modeling engines to create a sensor-simulation-data integration platform that can accurately and quickly identify vulnerable spots. Although a number of issues have been analyzed and discussed, much remains to be done in the field of data integration.

2 Classification of the systems monitoring oil pipelines maintenance

There are many types of the oil pipelines monitoring systems with unique feature and operational condition that have been studied (table 1).

Table 1. Classification of controlled parameters and monitoring systems

Type of parameters	Values	Monitoring System
Geometric	Linear dimensions, linear and angular movements, bending radius, oscillation amplitudes	Inline inspections, additional defectoscope control
Technological	Tenso- and vibro- parameters, product\wall temperatures, distribution of protection voltage, metrological parameters, characteristics of pumpage product	Remote data acquisition and control system (RDACS), Leak detection system (LDS), Corrosion protection system (CPS)
Seismic	Vertical and horizontal ground vibration and movement	Seismic effects monitoring system (SEMS)
Geological	Location and size of dangerous geological processes, humidity and density, strength, plasticity and soil deformation module, filtration factor, ice content, degree of heaving, salinity, porosity, heat, corrosive activity	GIS, subsurface exploration, aerial survey, remote sensing, geodetic measurements
Geotechnical	Ambient temperature, soil and permafrost temperature, temperature and level of groundwater, efficiency and effectiveness of the thermostabilizers, the depth of the seasonal freezing defrosting	System of geotechnical monitoring (SGM)
Geophysical	Depth of the oil seams, geoelectric conditions	GIS, geophysical surveys
Mechanical	Metal Characteristics (wall thickness, steel mark, diameter, chemical composition, type and category of tubes), weld characteristics, insulation parameters, rheological characteristics	Electronic passport of pipes and pump stations' equipment
Environmental	Water specimen (temperature, component composition, acidity, current velocity, flow), air, pairs of oil products from reservoirs	Environmental monitoring system

In the daily operation of oil pipelines, a lot of decisions have to be taken that affects the volumes produced and the cost of production. These decisions are taken at different levels and related to the choke/valve openings, compressors, pump settings, etc. at every instance of time. These are the control elements of RDACS [5]. RDACS is a geographically distributed hierarchical computer system, that combines automation and telemechanization equipment. It bases on information of pressure sensors, level sensors, temperature measurements, and solves the following tasks:

- analysis of the volume of oil and petroleum products and their quality;
- leakproofness control,
- monitoring the electrical equipment and electrical supply parameters;
- calculating technological process based on a hydraulic model.

LDS, by itself, has no effect on the technical integrity of the pipeline as it is only installed to make the operator aware of a leak in order for the operator to manage the risk of pipeline failure [6]. Leak detection techniques based on the mass balance model, the dynamic model, using hydraulic equation, the pressure deviation model. It is a set of real-time software tools, based on the specified algorithms, which perform a rated accuracy function of continuous control of the leakproofness of a pipeline section. They are designed to detect leakage, measure, place, and time.

The first important aspect related to the seismic response of civil and industrial constructions is the proper measurement of the shaking level at the site of interest [7]. The SEMS is a program apparatus complex consisting of [8]:

- a network of seismic stations, installed along a pipeline route,
- pairs of seismic sensors, connected to seismic stations and installed in specially equipped wells,
- signal detection and processing programs installed at the control points,
- archives of receiving information.

When a seismic event occurs, the SEMS determines the level of danger for a pipe and pump stations and gives warning or stop signals.

The SGM estimates the displacement of ground by inclinometric control points, groundwater control points to calculate the stability of the landslide slopes, the points of control of a pipe position to assess the effects of loads in the development of dangerous geological processes [9].

The problem of data integration became more acute as far as enlisted monitoring systems work independently with sensors controlling only their technological parameters without knowing what is happening to the others. The solution of the problem is a human-operator who makes decisions. As a result, the quality of monitoring depends on experience and skills of operators. From the safe operation point of view, functional separation of controlled parameters is an artificial technique. There is a need to reduce its negative effects so that an information flow reflects a real change in pipeline maintenance. The trend of pipeline monitoring systems development wends the way of centralizing the top level to meet the challenge of complex, interrelated control of all sets of parameters, as well as to provide users with access to measurement data from any of the terminal devices of the corporate computer network.

Thus, a significant number of control nodes that are remote from each other for thousands of kilometers and equipped with heterogeneous sensors, the independence of contours over controlled parameters lead to an uncontrolled increase in the amount of initial information and need to develop methods for integration of distributed diverse information.

3 Requirement analysis

The detailed analysis of background information and technical reports let us to formulate a list of requirements for integration of data from different monitoring systems. We can group them into three broad types, namely: 1 - harmonizing, 2 - combining and 3 - merging. First group includes stages of interaction with sensors, estimation of reliability and quality of source data, analysis of data structures, restoring dimensions, description in terms of subject areas, formatting. Second group will consist in noise\trends detection and elimination; deduplicate and restore data; statistical processing and calculations with validation of the result. Last group contains merging at data and relation levels, deep learning of prepared data, modeling and forecasting.

4 Integration at the hardware and software architecture levels

Sensors installed in thousands locations along the route, produce values of the controlled parameters in real-time regime. They are recorded in local databases and archives of different structures and formats (Fig. 2). It laid the foundation for designing a computational suprasystem that contains web-services operating with every class of process, global database and archives storing data, and computational methods.

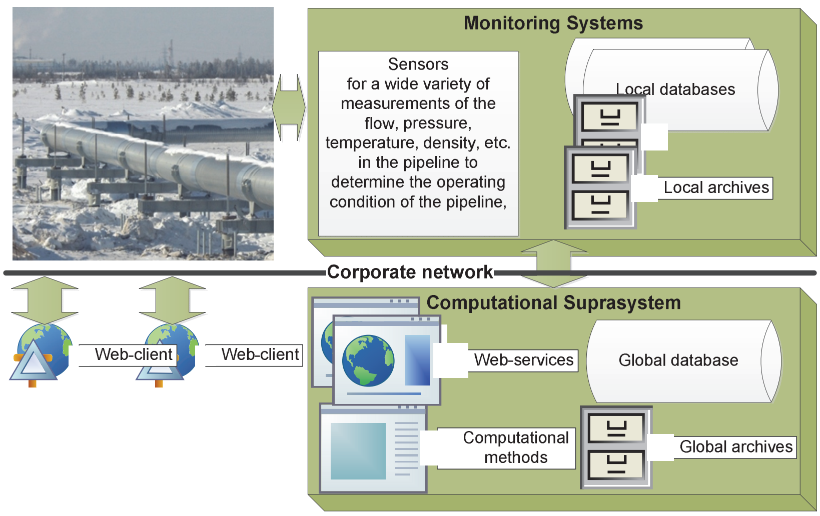

Fig. 2. Hierarchic monitoring system

5 Data-level and user-type integration

Each monitoring system that collects data is designed for the specific purpose of certain types of users, but same data may be useful for other types of users (economists, managers). Preliminary analysis of user profiles allows to develop specified methods for locating patterns in separate and intersecting sets of data and to interpret them correctly. For example, modeling thermal fields along the pipeline route and selecting subsequences from measurements, are typical for sustainable soil defrosting and allow early detection of anomalies and classification of the route segments.

Algorithms for detecting similar subsequences, use of search optimization techniques (indexing, dismissing unlike subsequences), various similarity measures, and dynamic transformation of the timescale that allows comparison of time series obtained at different speeds of data change. A discrete Fourier and wavelet transformations, suffix trees, and others are used to build the spatial index.

Data integration process can be described as follow [10]:

R = <Rs, Rd, Rv, Rr>,

where Rs – a set of process classes; Rd – a set of subject areas; Rv – a set of processes, structured according to Rd; Rr – a set of relationships between Rs and Rv.

As far as data integration process is layered, R can be detailed for processes of different levels. A flow of raw data is accepted for preprocessing and a partial aggregation is generated, which then adds the preprocessed data from another monitoring system. The result of iterations is a complex aggregation.

Thus, novelty of the proposed approach is include:

- the service-oriented architecture, absorbing installed monitoring systems;
- the methodology for implementation and remote deployment of a suprasystem;
- verification of actual values of the controlled parameters;
- identification wrong trends and noticeable variances in the controlled parameter values;
- optimization of a number and frequency of the controlled parameters;
- plans to implement compensating activities.

6 Results Discussion

Pipeline operators face many threats to the integrity of pipelines. The proposed suprasystem is based on data flows and knowledge-retrieval techniques that make it possible to shape control effects by combining real-time data with already available information. At the stage of integrating data, received from multiple sensors and affixed to the available information (meteorological and geological data) we produce additional information, that is valued by ecologists, economists, geotechnicians and others. It is possible to analyze data with a variety of devices that recognize context of a corporate computer network. Using deep-learning algorithms that indicate patterns in data, it is possible to predict pipeline's maintenance.

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