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Leak detection of pipeline: An integrated approach of rough set theory and artificial bee colony trained SVM

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ABSTRACT

The generation of leak along the pipeline carrying crude oils and liquid fuels results enormous financial loss to the industry and also affects the public health. Hence, the leak detection and localization problem has always been a major concern for the companies. In spite of the various techniques developed, accuracy and time involved in the prediction is still a matter of concern. In this paper, a novel leak detection scheme based on rough set theory and support vector machine (SVM) is proposed to overcome the problem of false leak detection. In this approach, 'rough set theory' is explored to reduce the length of experimental data as well as generate rules. It is embedded to enhance the decision making process. Further, SVM classifier is employed to inspect the cases that could not be detected by applied rules. For the computational training of SVM, this paper uses swarm intelligence technique: artificial bee colony (ABC) algorithm, which imitates intelligent food searching behavior of honey bees. The results of proposed leak detection scheme with ABC are compared with those obtained by using particle swarm optimization (PSO) and one of its variants, so-called enhanced particle swarm optimization (EPSO). The experimental results advocate the use of propounded method for detecting leaks with maximum accuracy.

1. Introduction

In the industries consisting of fluid pipe networks, leaks occur principally by the aging of pipeline, faulty installation, material defects, corrosion/erosion of external and internal walls, digging and construction works near the pipelines. The losses owing to pipe leakage are mainly due to the downtime of transportation service that results in delayed supply of channeled material, the maintenance cost of damage, and loss of transported product. More importantly, if the transported material is petroleum or other oil products, leaks can be extremely hazardous resulting in pollution, injuries and can even be fatal. Therefore, in the recent years, there has been a general consensus pertaining to the problem of fast detection and localization of damages along the pipeline to save public lives and prevent economic losses. The various approaches available for leak detection is classified into hardware and software based methods. In hardware based methods, optical fibers or special sensors (acoustic sensor, chemical sensor, etc.) are used to detect changes in surrounding environment due to leakage. The software based techniques uses software packages to continuously monitor process variables such as pressure and flow rate to signal the generation of pinpoint leaks.

Furthermore, for localization of leaks, the so-called negative pressure wave (NPW) based method (sensible to serious leaks) has found to be the most prevalent one. The fundamental principle of NPW based method is as follows; when leak generates, a rapid pressure drop occurs at the leak point, i.e. negative pressure wave forms. This wave travels from the leak point to the sending and receiving terminals of pipeline with the acoustic velocity, consequently, changes pressure at both the terminals. The leak is identified by detecting the pressure changes at the ends using installed pressure transducers. The precise synchronization of transducers sampling clock at the inlet and outlet of pipe is usually achieved by satellite navigation system GPS. In addition, the point of leakage is calculated by transferring acoustic speed of negative pressure wave and difference of arrival times of negative pressure wave at both ends (Feng, Zhang, & Liu, 2004). Another method, named pressure gradient method has proved to be effective for localization of weak leaks. In this method, localization of leak can be done by measuring the pressure gradient near inlet and outlet of the duct and utilizing the mathematical formula derived from continuity and momentum equation in terms of pressure gradients, inlet and outlet pressure and length of pipe (Feng et al., 2004).

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Various other tools have been developed and implemented by the researchers in the domain of leak detection and localization problems. In this paper, a novel approach that encompasses rough set theory and support vector machine (SVM) in conjunction with artificial bee colony (ABC) algorithm has been applied to improve the accuracy with reduced time of prediction of leaks along the pipeline carrying crude oil and liquid fuels. The rough set theory is applied to generate rules by mining simulated data set initially so that input parameters and length of data set can be reduced. The generated set of rules is employed as a guideline for detection service in order to accomplish direct inspection of abnormalities. Further, the classifier function of SVM has been used to finally inspect remaining doubtful cases. The support SVM which is a variant of artificial neural network (ANN) algorithm, proposed by Vapnik (1995), has emerged as an effective tool for solving classification and regression problems. While literature survey, various successful applications of SVM was found including; Niu, Wang, and Wu (2010) for power load forecasting, Serapião, Tavares, Mendes, and Guilhermi (2006) in classification of petroleum well drilling operation, Claudio, Rocco, and Zio (2007) for classification of transients in nuclear power plant, Arun and Gopal (2009) for pattern classification, Chen (2007) for forecasting reliability of turbocharger engine system and Huang, Chen, Hsu, Chen, and Wu (2004) for corporate credit analysis.

Inspired by aforementioned approaches, this paper implements SVM for investigation of presence of leaks. A practical difficulty that arises before using SVM classifier function in the diagnosis scheme is the need for optimum values of support vectors for each case of training dataset. It is very ineffective to use classical nonlinear optimization algorithms to train SVM (Yuan, Zhang, Zhang, & Yang, 2006). Thus, in this research, swarm intelligence technique known as ABC has been implemented to search suitable values of support vectors that could maximize detection accuracy. In order to judge the performance of ABC for the problem tackled in this study, the obtained results are compared with those achieved by particle swarm optimization (PSO) and one of its variants named as enhanced particle swarm optimization (EPSO).

The remainder of this paper is organized as follows: Section 2 summarizes the previous work in the context of leak detection and localization problem. Section 3 describes the leak detection and localization problem in detail and also provides detail of rough set theory. The developed leak detection scheme has been elaborated in Section 4. In Section 5, overview of ABC, PSO, and EPSO algorithms is presented. The Section 6 summarizes computational experience and the subsequent subsection analyzes the performance of applied algorithms. Section 7 presents the conclusion and future scope of the research work.

2. Literature review

Numerous researches have been carried out in the area of pipeline networks for the detection and localization of leaks. Kolczynski, Tylman, and Anders (2010) presented modern numerical algorithms – neural network and probabilistic network – to detect fluid leaks in pipe type cable installations. Qu, Zeng, Zhuge, and Jin (2010) proposed a SVM based leak detection and warning system. The SVM was used to recognize vibration signals generated due to leakage. The recognition correct rate of technique was good and now it is operating on four pipelines with a total length of around 150 km. Zhou, Hu, Yang, Xu, and Zhou (2009) proposed a belief-rule-based (BRB) expert system for leak detection. Turkowski, Bratek, and Slowikowski (2007) discussed several methods of leak detection and localization problem. Kim and Lee (2009) performed a time–frequency analysis for detecting leaks in buried gas pipe. Zhang, Jin, Yang, Wang, and Bai (2006) solved leak detection problem of oil-transporting pipeline by detection changes in pressure and flux at the same time. Zhang (1992) measured the process variables such as pressure and flow rate at both ends of pipe and implemented statistical technique for the detection and localization of leaks. Vaz, Medeiros, and Araujo (2010) used time series black box strategy for detection, location and quantification of leaks in large pipeline system. They developed two time series resources: detector and the localizer. Yang, Xiong, and Shao (2010) resolved the problem and developed a leak localization technique for the pipelines based on wavelet analysis. The work of Elaoud, Taieb, and Taieb (2010) detected leaks of hydrogen-natural gas mixtures in pipeline by means of transient analysis. They found that transient pressure is much more important in the case of hydrogen than in the case of natural gas. Tylman, Kolczynski, and Anders (2010) presented a fully automatic system to detect leaks of dielectric fluid in underground high pressure cables. They integrated a number of AI techniques and data processing techniques to achieve high detection accuracy.

Belsito, Lombardi, Andreussi, and Banerjee (1998) developed a method for determining leak size and location using artificial neural network: the system successfully detected leaks as small as 1% of inlet flow rate and accurately localized leaks with a probability of success greater than 50% for small leaks. Mpesha, Gassman, and Chaudhry (2001) utilized frequency response method to determine location and rate of leakage in open loop piping system. In this method, a steady-oscillatory flow produced by the intermittent opening and closing of a valve is analyzed in the frequency domain by using the transfer matrix method, and a frequency response diagram at the valve is plotted. If leaks are present along the pipeline, the diagram shows additional resonant pressure peaks that are lower than the resonant pressure amplitude peaks for the system with no leaks. After analyzing the model on several pipelines for different practical values of friction factor, they concluded that the model could detect and locate individual leaks of up to 0.5% of the mean discharge. Misiunas (2005) presented a new technique called continuous monitoring approach, which falls under a classification known as time domain reflectometry (transmission and reflection of pressure waves), for detecting and locating leaks along the pipelines. This method measures the pressure at one location of pipeline to sense the presence of negative pressure wave and determine the location of leak by timing of initial and reflected transient wave produced due to leak. But the leak detection and localization accuracy of model fails when leak opening time is larger than the traveling time of wave from the leakage point to the sending and receiving terminal of pipeline.

Chen, Ye, and Lv (2004) utilized the concept of formation of NPW and applied SVM to check the presence of leaks. The system used pressure values – recorded once in a 60 ms from the pressure curve, as the input feature vector for the SVM. They showed that the detectable accuracy was 90.33%. Feng et al. (2004) approached the problem using fuzzy decision making where decisions were made based on the five features as: inlet pressure, outlet pressure, inlet flow rate, outlet flow rate and difference of inlet to outlet flow rate. As aforesaid, NPW method is more sensible to serious leaks whereas the sensitivity of gradient method is more sensible in case of weak leaks. Feng et al. (2004) integrated both the methods and tested to pinpoint leak points along a pipeline of 14.117 km long with an inner diameter of 273 mm and the sending pressure of 0.4 Mpa. They have successfully detected all the leaks with an average localization error of 190 m.

Most of the approaches discussed above inspects leak only one time. As a result, pin-point leakages could not be detected accurately. In order to improve accuracy, this paper proposes a new multi-stage leak detection method. As mentioned earlier, first rules generated by rough set theory do the task and then SVM classifier function is utilized to re-check presence of leaks. Rough set theory, since its inception by Pawlak (1982), has been attracting attention