Expert Systems with Applications 40 (2013) 1925–1934

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

# Oil and gas pipeline failure prediction system using long range ultrasonic transducers and Euclidean-Support Vector Machines classification approach

Lam Hong Lee [a,*], Rajprasad Rajkumar [a,1], Lai Hung Lo [b,2], Chin Heng Wan [b,2], Dino Isa [a,3]

[a] Intelligent Systems Research Group, Faculty of Engineering, The University of Nottingham, Malaysia Campus, Jalan Broga, 43500 Semenyih, Selangor, Malaysia
[b] Faculty of Information and Communication Technology, Universiti Tunku Abdul Rahman, 31900 Kampar, Perak, Malaysia

ARTICLE INFO

*Keywords:*
Oil and gas pipeline defects
Long range ultrasonic transducer
Support Vector Machines
Euclidean distance function
Kernel function
Soft margin parameter

ABSTRACT

This paper presents an intelligent failure prediction system for oil and gas pipeline using long range ultrasonic transducers and Euclidean-Support Vector Machines classification approach. Since the past decade, the incidents of oil and gas pipeline leaks and failures which happened around the world are becoming more frequent and have caused loss of life, properties and irreversible environmental damages. This situation is due to the lack of a full-proof method of inspection on the condition of oil and gas pipelines. Onset of corrosion and other defects are undetected which cause unplanned shutdowns and disruption of energy supplies to consumers. Existing failure prediction systems for pipeline which use non-destructive testing (NDTs) methods are accurate, but they are deployed at pre-determined intervals which can be several months apart. Hence, a full-proof and reliable inspection method is required to continuously monitor the condition of oil and gas pipeline in order to provide sufficient information and time to oil and gas operators to plan and organize shutdowns before failures occur. Permanently installed long range ultrasonic transducers (LRUTs) offer a solution to this problem by providing an inspection platform that continuously monitor critical pipeline sections. Data are acquired in real-time and processed to make decision based on the condition of the pipe. The continuous nature of the data requires an automatic decision making software rather than manual inspection by operators. Support Vector Machines (SVMs) classification approach has been increasingly used in a multitude of domains including LRUT and has shown better performance than other classification algorithms. SVM is heavily dependent on the choice of kernel functions as well as fine tuning of the kernel and soft margin parameters. Hence it is unsuitable to be used in continuous monitoring of pipeline data where constant modifications of kernels and parameters are not unrealistic. This paper proposes a novel classification technique, namely Euclidean-Support Vector Machines (Euclidean-SVM), to make a decision on the integrity of the pipeline in a continuous monitoring environment. The results show that the classification accuracy of the Euclidean-SVM approach is not dependent on the choice of the kernel function and parameters when classifying data from pipes with simulated defects. Irrespective of the kernel function and parameters chosen, classification accuracy of the Euclidean-SVM is comparable and also higher in some cases than using conventional SVM. Hence, the Euclidean-SVM approach is ideally suited for classifying data from the oil and gas pipelines which are continuously monitored using LRUT.



## 1. Introduction

This paper presents a novel oil and gas pipeline failure prediction system by utilizing non-destructive testing (NDTs) method based on long range ultrasonic transducers (LRUTs), in conjunction with an advanced signal processing technique and a new classification framework, the Euclidean-Support Vector Machines (Euclidean-SVM) approach. This system provides continuous monitoring for pipelines using NDT method, and also makes decision without human errors and misinterpretations using artificial intelligence classification approach. In recent years, oil and gas pipeline condition monitoring and failure prediction system has become great importance, due to the incidents of oil and gas pipeline leaks and failures which happened around the world. These incidents are becoming more frequent and have caused loss of life, properties and irreversible environmental damages. The major cause of these incidents is the lack of a full-proof method of inspection on the condition of oil and gas pipeline. Corrosion has been reported as

* Corresponding author. Fax: +603 89248017.
*E-mail addresses:* leelamhong@gmail.com (L.H. Lee), Rajprasad.Rajkumar@nottingham.edu.my (R. Rajkumar), laihung@hotmail.my (L.H. Lo), wanchinheng@yahoo.com (C.H. Wan), Dino.Isa@nottingham.edu.my (D. Isa).
[1] Tel.: +603 89248377; fax: +603 89248017.
[2] Tel.: +605 4688888; fax: +605 4661672.
[3] Tel.: +603 89248116; fax: +603 89248017.

0957-4174/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2012.10.006

one of the major problems in oil and gas pipeline which results in catastrophic pollution and wastage of raw materials (Lozev, Smith, & Grimmett, 2003). These undetected defects of pipeline cause unplanned shutdowns and disruptions of energy supply to the consumers. Hence, frequent leaks of gas and oil from the pipeline due to ruptured pipes are calling for the need for better and more efficient methods to monitor the condition and predict the failures of oil and gas pipeline.

Since some decades now, techniques such as pigging (Lebsack, 2002) have been used for pipeline inspection at predetermined intervals. The pigging technique uses devices called smart pigs, which travel within the pipeline to record critical information such as corrosion levels, cracks, and structural defects using numerous types of sensors. Smart pigs are able to provide pinpoint information on the location of defects using techniques such as magnetic flux leakage and ultrasonic detection (Bickerstaff, Vaughn, Stoker, Hassard, & Garrett, 2002). However, the implementation of pigging system in pipeline inspection can be very costly, and the pipeline condition is measured only at the instance it is deployed and does not provide continuous measurements over time. Recently, other NDT techniques have also been introduced to monitor the condition of pipelines in order to reduce the cost of using pigging system for pipeline inspection. However, these NDT methods have also been implemented at predetermined intervals, where operators need to be physically present to perform measurements, data collection and make judgments on the integrity of the pipeline. These processes may take up to several months in order to generate the result regarding to the condition of the pipeline. During this period, the condition of the pipeline can go unmonitored, and hence may cause failures and leaks, as the defects which lead to these failures may occur suddenly.

In order to overcome the problems as mentioned above, a full-proof and reliable inspection method is required to continuously monitor the condition of oil and gas pipeline in order to provide sufficient information in a real-time manner to oil and gas operators to plan and organize shutdowns of the pipeline before failures occur. A permanently installed NDT system is needed for real-time pipeline condition monitoring and failures prediction by providing an inspection platform that continuously monitors critical pipeline sections, such as insulated pipes, risers, pipes on hill slopes, pipe bends, pipes under road crossings and offshore pipes. This system would ensure that pipes are continuously monitored and hence prevent the occurrence of leaks and failures. LRUT which utilizes guided waves to inspect long distances from a single location (Demma, Cawley, Lowe, Roosenbrand, & Pavlakovic, 2004), was specifically designed for inspection of Corrosion Under Insulation (CUI). As compared to other NDT techniques, LRUT is reported to be more efficient and cost-saving, since it also able to detect both internal and external corrosions. This makes LRUT technique to have many advantages over other NDT techniques which have seen their widespread use in many other applications. With recent developments of oil and gas pipeline which are based on permanent mounting system using special compound, a real-time continuous monitoring system is destined to be the future trend of NDT systems. Data from the permanently installed LRUT system will be continuous and hence not practical to be analyzed by human operators. In our proposed system, data are acquired in real-time and processed to make decision based on the condition of the pipe. The continuous nature of the data requires an automatic decision making software rather than manual inspection by the human operators. Hence, automatic and intelligence-based software must be deployed to the system in order to process the continuous streams of data and make decisions on the integrity of the pipeline monitored.

Support Vector Machines (SVMs) approach has been increasingly used in a multitude of domains including LRUT and has shown better performance than other classification algorithms (Diederich, Kindermann, Leopold, & Paass, 2003; Isa, Lee, Kallimani, & Rajkumar, 2008; Isa & Rajkumar, 2009; Joachims, 1998; Joachims, 1999; Joachims, 2002; Lee, Rajkumar, & Isa, 2012; Lee, Wan, Rajkumar, & Isa, 2012; Wan, Lee, Rajkumar, & Isa, 2012). It can be used as a discriminative classifier and has shown to be more accurate than most other classification models (Chakrabarti, Roy, & Soundalgekar, 2003; Isa et al., 2008; Yang & Liu, 1999). The good generalization characteristic of SVM is due to the implementation of Structural Risk Minimization (SRM) principle, which entails finding an optimal separating hyper-plane, thus guaranteeing the highly accurate classifier in most applications. Previous work has shown that SVM has provided excellent generalization performance for the LRUT pipeline failure prediction system, and the combination of discrete wavelet transform and SVM led to high accuracies for predicting failures in pipelines (Isa & Rajkumar, 2009). However these results were generated without having the continuous scenario in mind. The good classification performance of SVM is only guaranteed when the classification model is implemented with the appropriate combination of kernel function and parameters. According to the principle of SVM, one of the critical problems of SVM classification approach is the selection of appropriate combinations of kernel function and parameters, in order to obtain high classification accuracy. It does not have a generally optimal combination of kernel function and parameters which is able to guarantee maximal classification performance for all types of data. Hence, for an online and continuous scenario, the conventional SVM is unsuitable to be used in continuous acquisition and processing of pipeline data where frequently tunings of kernels and parameters values are unrealistic and impractical.

In recent years, many research works have been carried out with the same goal that is seeking for the solutions to counter the problem of obtaining an optimal combination of kernel function and parameters for SVM. Typically, convoluted computations such as grid search (Hsu & Lin, 2002; Staelin, 2003) and evolutionary algorithms (Avci, 2009; Briggs & Oates, 2005; Diosan, Rogozan, & Pecuchet, 2012; Dong, Xia, & Tu, 2007; Friedrichs & Igel, 2004; Quang, Zhang, & Li, 2002; Zhang, Shan, Duan, & Zhang, 2009;) have been proposed for the optimization of the combination of kernel function and parameters for the SVM models. This could be done by conducting iterative cross-validation process to predict the best performing combination of kernel function and parameters for the trained SVM classifier, using a validation set. This method leads to a computationally intensive and high time-consuming training process, hence degrades the efficiency of the classifier. To date, there is no ultimate solution of having an all-rounded and optimal combination of kernel function and parameters which will suit most of the SVM classification tasks. Therefore, in our previous work (Isa & Rajkumar, 2009), we found that one of the weaknesses of the pipeline failure prediction system using the conventional SVM approach is the necessity to identify the optimal combination of kernel function and parameters, in order to obtain high predicting accuracy for the presence of defects in oil and gas pipeline. Furthermore, for certain cases in which the training samples are limited, such as the proposed pipeline failure prediction system in this paper, there exists a critical problem in real world scenario in preparing sufficient training set and validation set to train the classifier and to conduct the kernel function and parameters optimization process. As the usage of LRUT technique for pipeline failure prediction is still in an early stage of investigation, research and development, there is a great obstacle in obtaining well-organized and analyzed sample data to construct sufficient training set and validation set for the SVM model.

In this paper, we propose the Euclidean-SVM classification framework to be used in conjunction with the NDT method based on LRUT technique to perform continuous condition monitoring