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PIDSS and Leak Detection with Petri Nets Controller

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Abstract. Pipelines Intrusion Detection Security System (PIDSS) has been long used in pipeline routes to detect leak and third party intrusion interference. Fiber optic Distributed Temperature Sensing (DTS) method equipped with laser technology has been often successfully applied. The use of the fiber optic for such purpose has paved the way to mix the telecommunication applications with the security on the same cable that can be used for computer and telephony telecommunication purposes. In this paper a brief basis and concept of its technology with industry deployment application case has been presented. The proposed future work will be in realizing a controller based on the Petri Net Object Oriented Data Structure (PNOODS).

Keywords: Fiber optic sensor, PIDSS, leak detection, ground movement detection, DTS, OTDR analysis, and PNOODS.

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1. Introduction

In general, pipelines performance and its system security became crucial to safety and reliability. Therefore, the use of fiber optic distributed temperature sensing has been matured and trusted due the increasing research and development. While laser power and accuracy as well as signal collection and treatment continues to be the differentiating factor among the various distributed temperature sensing, the principle of the technology remained largely the same. The other advantages of utilizing distributed fiber optic sensing in monitoring pipelines include the ability to adequately monitor the profile of pipeline sections during operation on cool down and warm up cycles.

Apart from the temperature profiling of pipe and containment, fiber optic sensors also offer an intrinsically containment safe and non-intrusive monitoring. The system provides continuous detection and monitoring in all weather conditions, being immune to EM and RF interference and being capable of being run alongside high voltage power cables.

Except the controller, there is no power needed since the cable is inert only passing emitted and reflected laser signals. The reflection characteristics of the traveling light vary with temperature and other physical parameters like strain and vibration. Further, the cable unused fibers can be used for telecommunication purposes such telephony and computers networking. With this type of systems, the design and building of the controller is a major and important issue.

2. Technology Overview

The Distributed Temperature Sensing (DTS) system is acoustic, and operates by detecting all seismic and acoustic events happening in the vicinity of the fiber optic cable. The system operates using a modified and highly Optical OTDR device and relies on monitoring the coherent Rayleigh backscatter noise signature of sensing cable. The sensing controller is connected to one end of the cable so it sends pulsed laser light into the fiber that is sensed when it is reflected back [1].

The fiber is usually standard telecommunication grade that does not contain any grating, splices or other transducers. It requires no power along the entire sensing length, but only at the sensing controller. Various cables can be chosen for either or both leak and ground movement detection depending on varying soil characteristics and pipeline installation procedures. The combined information of structural conditions and pipeline temperature is transferred to the SCADA system, while CCTV surveillance can also be included [2].

A leakage or intrusion incident is identified and located by the analysis of temperature profiles. Attainable detection limits are within the 0.01% range of total throughput for oil leaks. Such range is even lower for pressurized gas. The distance between measurement points along the sensing fiber is referred to as the spatial resolution of the system.

3. Sensing Principle

As mentioned, distribution sensing begins by relying on the OTDR readings that are affected by Rayleigh scattered light for measuring the attenuation profiles of long-haul fiber optic links. In this technique, optical time-domain pulses are inserted into the fiber and a photo detector measures the light amount that is scattered backwards while the pulse is propagating along the fiber.

The detected Rayleigh signal is an exponential decline with time, which is directly associated with the linear attenuation of the fiber. Time information is converted to distance information, in addition to fiber loss information. OTDR profiles are greatly useful for the localization of fiber breaks, the evaluation of splicers and connectors, and in general, for the assessment of the overall quality of a fiber optic link.

Raman and Brillouin scattering phenomena have been recently used for distributed sensing applications. Raman was firstly proposed for sensing applications in the eighties [3], while Brillouin was proposed later on to as a method to enhance OTRD range [4] and then, it was introduced for use in temperature monitoring applications [5]. Fig. 1 is a scheme that demonstrates the scattered light's spectrum from a single wavelength λ_o in optical fibers.

Both Raman and Brillouin scattering effects are associated with various dynamic non-homogeneities of the silica and thus, they have completely varying spectral characteristics.

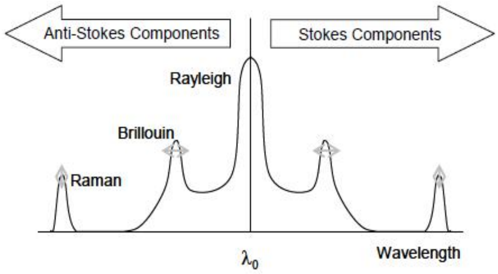

Fig. 1. A schematic electromagnetic representation of scatted light spectrum from a signal of a single wavelength, propagating in optical fibers. An increase in fiber temperature affects Raman and Brillouin components, while strain affects Brillouin components only.

4. Leak Detection

Leak detection is based on continuous accurate distributed temperature monitoring, along with a temperature measurement cable (TMC) that is located adjacently to the pipeline [6].

The pipeline's perimeter is cooled when the fluid is compressed. Then, leak detection is based on the Joules-Thompson or Throttling effect which is phenomenon seen by releasing compressed gas through an aperture or a porous material into an area of lower pressure [7]. While fluid is being retained within an adiabatic regime, any pressure change, as caused by a leak, for example, will lead to a temperature drop, affecting the TMC. Then, the interrogator detects the temperature change, from which it concludes leak detection and localization. Then, any small leak would cause a temperature increase within the pipeline's adjacency. The presence of a local hot spot along the sensing cable is a signature for a leakage.

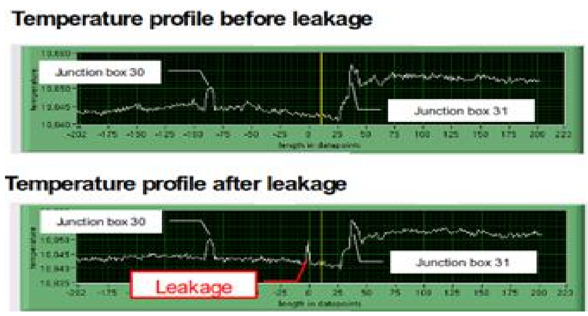

Fig. 2. Leakage detection and localization as triggered by excavation works within the pipeline's adjacency [8].

5. Deployment Performance

Typical detection distance and responses shown below are on a buried fiber, 1km range, test facility, 10 spatial resolutions, 5kHz bandwidth [9]. The fiber is buried at depths of 0.3-1.0m with the soil base being clay (actual on site detection will vary depending on composition and geology of the environment).

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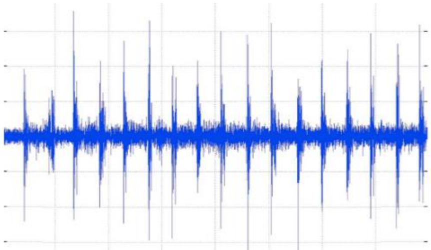

Fig. 3. Fiber Response to Footsteps along Buried Fiber [8]

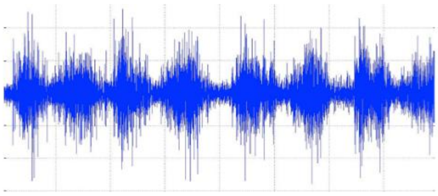

Fig.4. Illustration of the Fiber Response generated by Brushing a Chain Link Fence with a Fence Mounted System [8]

The primary function requirements for Third Party Intrusion (TPI) and Leak Detection (LD) are continuous monitoring, zones definition and alarm thresholds, events localization and identification, self-start/re-start capability in addition to scheduling and storage capabilities that are needed for archiving or reviewing. Interfacing the system can be camera controlled, mobile/email communication, dry contacts, OPC, HTTP, or Web Components.

6. Object Oriented Petri Net

To graphically model industrial processes, Petri net is often selected. Petri net structure [11] is four tuples (P, T, I, O) where P = $\{p1, p2, ...pn\}$ is a finite set of places (events) while T =$\{t1, t2, ... tm\}$ is a finite set of transitions (actions). The set of places and the set of transitions are disjoint, $p \cap t = \emptyset$. I is an input function that defines directed arcs from places to transitions. O is an output function that defines directed arcs from transitions to places. Petri net is marked, i.e., contains tokens. Tokens (represented graphically by dots) reside in places, travel along arcs, and their flow through the net is regulated by transitions. A marked Petri net is defined by the quintuple PN = (P, T, I, O, m). The marking m is an n–dimensional vector whose *ith* component m(pi) represents token in the *ith* place p_i. The initial marking is denoted by m_0. The computation of all possible future markings starting from the initial marking can be drawn in the form of reachability tree. The marking m_r is said to be reachable form m_0 if there exists a firing sequence that will yield m_r. The set of all possible markings reachable from m_0 is called the reachability set, and denoted by $R(m_0)$.

Object-Oriented Petri net can be considered as a special kind of high level Petri net. In this class of nets, tokens are considered as instances or tuples of instances (entities) of object classes that are defined as lists of attributes. The marking therefore, is not tokens but entities [12].

7. Petri Net Simulation Proposal

Since the working principle is based on the temperature measurement of the Cable in the vicinity of the pipeline, a smart framework can be suggested for the controller that consists of three stages. The first stage is based on the received signatures and their thresholds. The second stage, based on a Petri Net (PN) that monitors OTDR signature values. The third stage regulates the identification and required responses [13]. The simulation evaluation and throughput shall be based on Object Oriented Petri Net Models [14].

8. Summary and Conclusion

The fiber optic based distributed acoustic sensing system has allowed a sensing controller to send laser light that is traveling through the fiber core as being a subject of thermal back scattering. The back scattering spectrum is cross-correlated with the original laser signal toward getting the controller service routines to detect any outside earth movement intrusion by third party or a pipeline leak.

In support of telecommunication the technology has well matured where even small movement nearby the fiber can be detected and identified. The identification has been improved by accurate and precise localization resulting in thousands of listening microphone along cable with many specific zoning. This conference paper here has introduced a case deployment example (Fig. 5) and a suggested PN approach for monitoring and controller development and throughput evaluation based on PNOODS for future work.

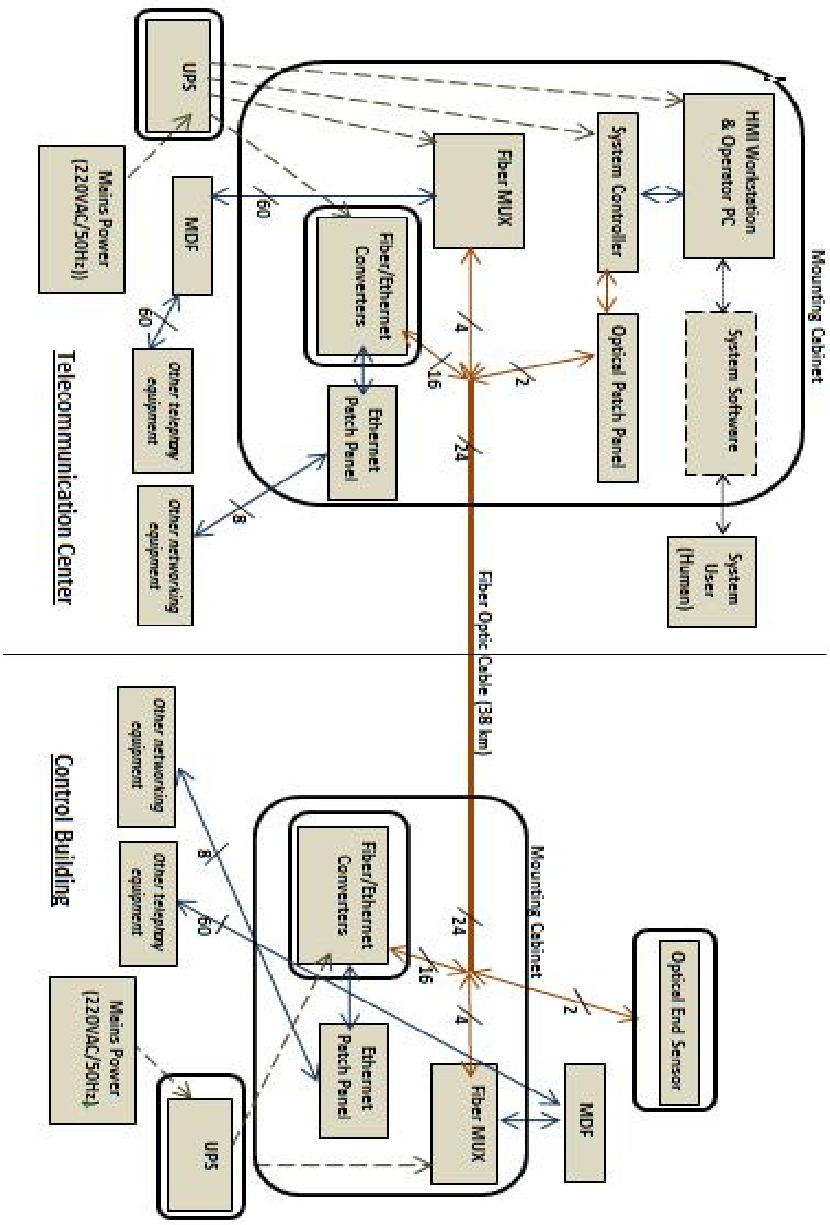

Fig. 5. Industrial Case Deployment Block diagram for Oil &Gas Pipelines Intrusion & Leak Detection [10]

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مجلة كلية العراق الجامعة للهندسة والعلوم التطبيقية

نظام امان اكتشاف اختراق خطوط الانابيب باستخدام متحكم بتري الصافي

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الملخص. لطالما استخدم نظام أمان اكتشاف اختراق خطوط الأنابيب على امتداد مسارات خطوط الأنابيب لاكتشاف التسرب وتأثير تداخل طرف ثالث. وغالبًا ما تكلل تطبيق طريقة استشعار درجة الحرارة الموزعة بالألياف الضوئية (DTS) المزودة بتقنية الليزر با لنجاح. إن استخدام الألياف الضوئية لهذا الغرض قد مهد الطريق لمزج تطبيقات الاتصالات مع تطبيقات الأمان على نفس الكيبل والذي بالأمكان استخدامه لأغراض اتصالات الكمبيوتر والهاتف. وتعرضنا في هذه الدراسة لأساس ومفهوم الطريقة بصورة موجزة مع تقديم حالة تطبيقة للتطور الصناعي .ومن مقترحات دراستنا البحث مستقبلاً تحقيق وحدة تحكم تعتمد في الأساس على بنية البيانات الموجهة لكائن أو بنية بتري الصافي.(PNOODS) .