Fiber optic based pipeline monitoring

Suzana Vale, Alexander Rauscher
PiMON GmbH, Germany
info@pi-mon.com

Abstract

PiMON is a German company specialized in fiber optic based acoustic sensor systems. We provide monitoring solutions for all kind of pipelines and perimeter security.

Our technology is inexpensive to install and operates largely automated. It deploys standard single mode fiber optic cables into a listening device for events. PiMON's system and its software interface is completely adjusted to our client's needs and substantially reduces the risk of pipeline damages and its devastating impact on the human and natural environment. On a real time basis our monitoring solutions are designed to:

- Prevent pipeline damages or leaks caused by construction work, farming, illegal tapping, sabotage etc.
- Protect critical assets from third-party interference.

The working principle behind our technology is the so called reflectometry effect. A single mode fiber cable is attached or buried nearby the pipeline or rail track. For telecommunication purposes such cables are very often already installed. As long as a dark fiber is still available it can be used for pipeline monitoring. In our system a short-time laser pulse is generated and sent continuously with a repetition frequency from 1 kHz to 11 kHz and a wavelength of 1.55 µm through the fiber. The laser pulse causes the Rayleigh backscattering signal in form of a reflectogram in which the time delay of the signal is shown as a distance on the cable. After receiving the optical signals, the pattern of these signals are digitalized and analyzed by a computer unit. Using a special algorithm the signals pass through digital filters and will then be compared with samples stored in the library. After categorizing the event, the system sends an alarm with the exact position through the internet via TCP/IP to the system operator and suitable countermeasures can be initiated.

1 Introduction

Oil, gas and water pipelines form a critical network all over the world and can easily be attacked by intruders. They are also susceptible to earthquakes, tsunamis and to any other geohazard incidents. Monitoring pipelines in order to keep them safe from damages is a major challenge. The long distances, often through remote and hostile territory, make the costs prohibitive for most conventional monitoring methods.

If an oil or gas pipeline is damaged it could have devastating impacts on:

- Human life and health due to explosions, fire and contamination;
- Environment due to poisoning of flora and fauna;
- Financial losses and damage to both image and reputation.

Leaks can be caused by unintended damages (construction work, farming), by deliberate acts (sabotage, illegal tapping) or just by failure (material fatigue, corrosion). When such events occur, it is imperative that their location is precisely and quickly located so that appropriate and effective countermeasures can be initiated.

According to a survey in 2009, about 36% of all pipeline leaks were caused by third party interference (TPI) like illegal tapping, sabotage or construction work[1]. Here are some examples:

- 04.10.2001 Fairbanks Alaska (USA), 990t oil due to sabotage;
- 2000 Tschernigow, Ukraine, 500,000 Liter diesel due to illegal tapping;
- 10.06.1999 Bellingham, Whatcorn Creek, Washington (USA), 880t petrol due to construction work, financial damage USD 45 million.

Illegal tapping is especially in emerging countries a major problem. In 2011 for example, Petroleos mexicanos (PEMEX) counted 1,324 cases of illegal tapping in Mexico. Every day they lose 40,000 liters of oil and gas[2]. Such damages could be avoided or reduced, if third party interference was detected before or close after it happens.

Despite all the effort to develop monitoring solutions to meet this challenge, there are only a few reliable solutions on the market available.

Many times the pipeline monitoring is done by walking-, driving- and flying-the-line. The annual costs for walking-and driving-the-line vary from €100 to €350 per kilometer. The additional costs for flying-the-line amounts to €4.50 per kilometer. Usually two inspections are performed per month, which adds up to €108 per kilometer (€4.50/km x 2 flights/month x 12 months). All in all the annual costs are between €208 and €458 per kilometer[3].

Compared to walking-, driving- and flying-the-line the costs for PiMON's fiber optic based acoustic monitoring solution are around €130,000 per 50 kilometer (including installation, service etc.). The total costs for one kilometer pipeline monitoring amounts to €2,600 a year. In relation to the above shown costs for walking-, driving- and flying-the-line, our system will be amortized within 5.7 to 12.5 years only. Not to forget that a fiber optic based pipeline monitoring system provides a true real time solution which substantially reduce the risk of direct, indirect and subsequent damages.

With PiMON's pipeline monitoring solution we are able to:

- Alert in case of emergency with accurate GIS location;
- Identify threats in real time in order to reduce the risk from leakages caused by digging, drilling, tapping, sabotage, earthquake etc.;
- Monitor 50 km of pipeline with one measuring unit without any additional power supply and with full scalability to cover deployments of any length by adding additional units;
- Avoid false or irrelevant alarms due to intelligent event recognition;
- Differentiate multiple events down to 5-15 meter resolution;
- Track potential intruders, moving in different velocities (vehicles or on foot);
- Detect direction and speed of the possible intruders;

- Monitor PIG's in real time;
- Provide perimeter surveillance.

2 Acoustic Fiber Optic Based Monitoring Solution

PiMON’s system is based on distributed fiber optical sensing and integrates an optical time domain reflectometer (OTDR), the analyzing and pattern recognition software, as well as a customized interface with GIS mapping. Very often the fiber optic cables are already buried or attached to the pipeline for telecommunication purposes. With PiMON’s technology we are able to deploy a standard single mode telecommunication fiber into a listening device for events.

2.1 Optical Time Domain Reflectometry (OTDR)

The OTDR is an optoelectronic instrument used to characterize optical fibers. It injects series of optical pulses into the fiber under test and then extracts, from the same end of the fiber the light that is scattered or reflected back from points along the fiber. It performs an efficient, precise and wide analysis of the fiber characteristics.

A laser diode launches light into one end of the optical fiber and a photo diode measures the reflecting light. The backscattered signal allows us to know exactly what happens along the fiber or close to it. The signal is influenced by both attenuation and reflections which the injected laser pulse experiences on its way through the fiber. If a certain area within the fiber has a higher degree of attenuation or reflection, this is detected through a different backscattered signal. Because of the known speed of the laser pulse, the exact location of the event can be determined by the difference of time between the injection of light and the return of the backscattered signal.

2.2 Optical Fibers

The characteristics of optical fibers make them a superior sensor.

- It is able to perform over long distances;
- Reflections of optical fibers change on vibrations (e.g. caused by vehicles, footsteps, digging, drilling), on temperature alterations (e.g. caused by escaping pressurized gas), or when optical fibers get strained, bent, kinked, or cut off;
- Localization of changed reflection (place of incident) is possible due to known velocity of propagation.

Figure 1: Change of Backscattered Signal

3. PiMON's Working Principle

With our system we use the so called Coherent Rayleigh OTDR. A short-time pulse is generated, amplified and launched into the fiber with a repetition rate from 1 kHz to 11 kHz and a wavelength of 1.55 µm.

On receiving end of the fiber the Rayleigh backscattering signals can be observed in form of a reflectogram in which the time delay of the signal incidence is shown as a distance on the cable. A very coherent laser is used in order to increase the sensitivity. Because of the high coherence an interference pattern can be observed in the backscattered signal (fingerprint). Vibrations cause temporary changes in this interference pattern.

The challenge of detecting third party interference, is to understand and filter out different events caused by manual or machine digging for instance. Every incident causes vibrations and changes the backscattering signals accordingly. After receiving such optical signals, the pattern of these signals are digitalized and analyzed within a computer unit.

By a special and very complex algorithm the patterns are passed through digital filters and then compared to samples stored in the library. After classifying the event, the system gives alarm through the internet via TCP/IP to the system operator.

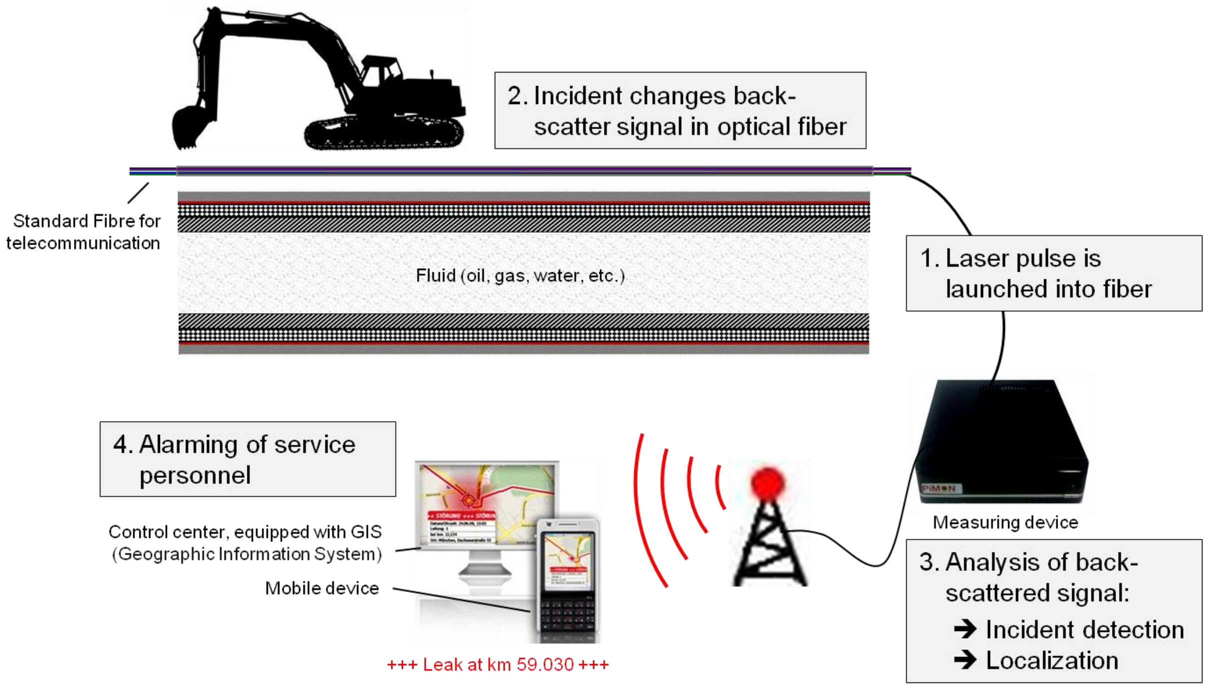

Figure 2: PiMON's Working Principle

As shown in figure 3, pipelines very often pass different (noise) environments. The software therefore needs to be specifically adjusted to the varying external conditions along the pipeline.

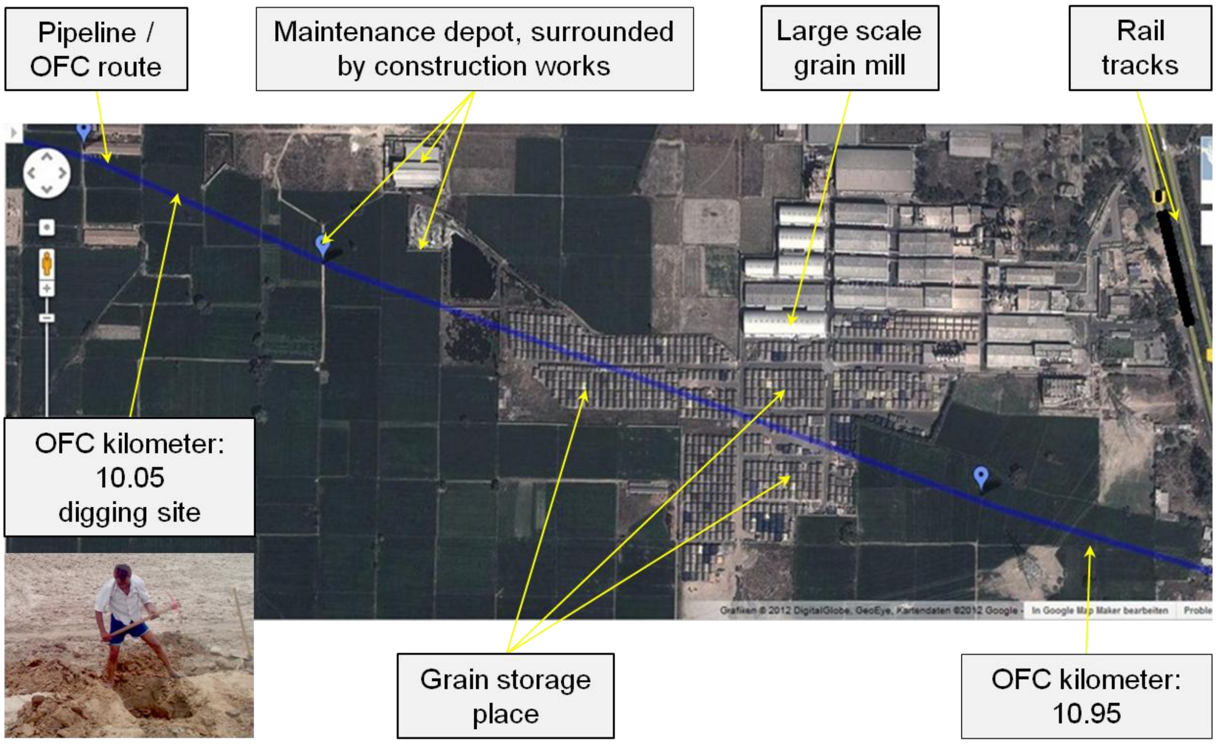

Figure 3: Pipeline Route nearby Delhi[4]

It is a major task to separate all regular sounds from possible threats. Furthermore the software has to be trained to distinguish important threats from common, inoffensive or irrelevant incidents. To meet this challenging task the system library is used to compare, recognize and classify all events as possible alerts or non-alerts.

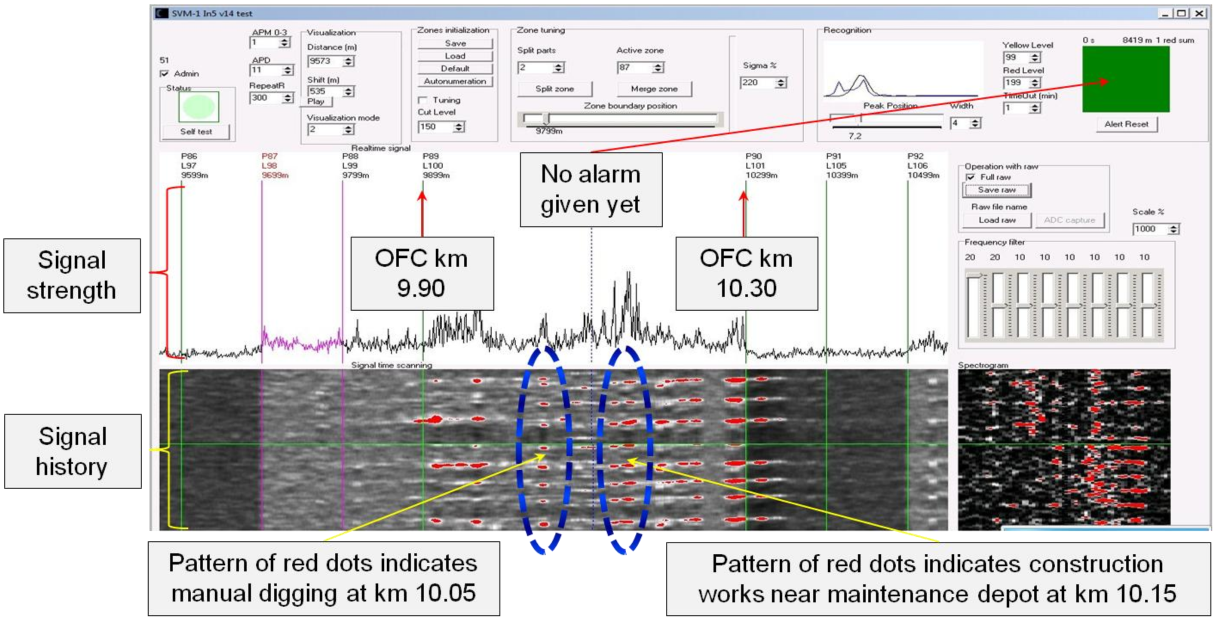

Figure 4: Software Principle (“Behind the Scene”)

Only if the sequence of a suspicious pattern of signals last for a specific time, an alarm will be shown and sent to the pipeline operator via an easy to understand user interface which comprises an event history file with time, date and location of all alerts. As a result effective countermeasures can be initiated accordingly.

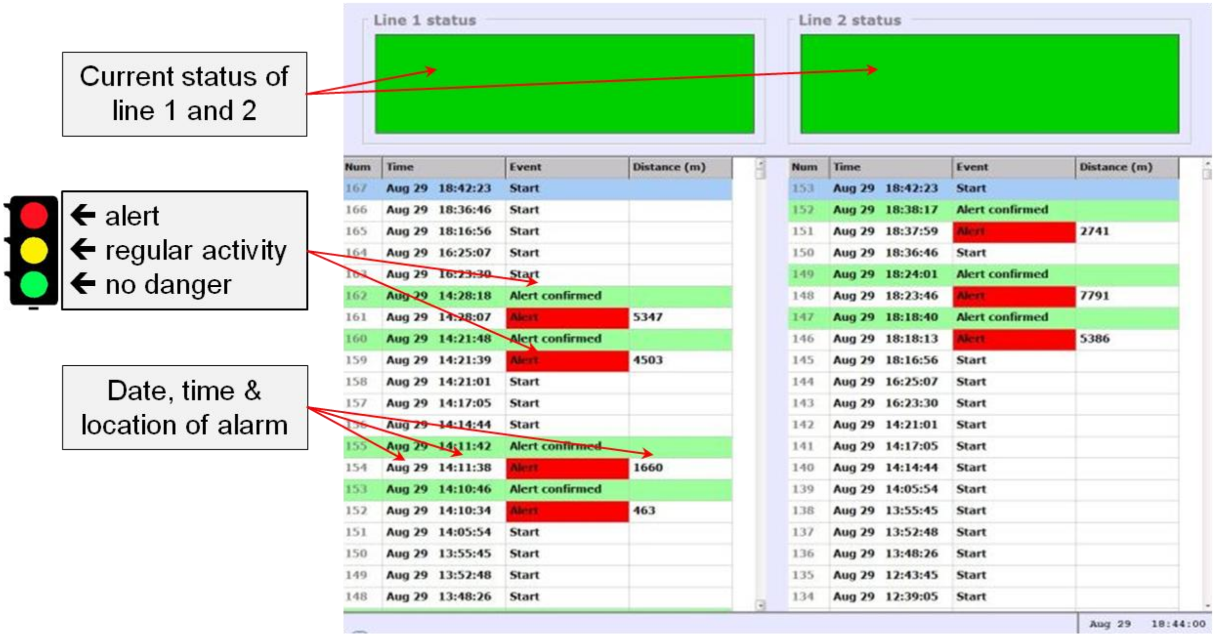

Figure 5: Graphical User Interface for Two Lines

4. Project in India – Detection of Third Party Interference

The Indian Oil Company (IOC) faces annual losses due to illegal tapping in the region of €200 million. We have been asked to install our system on a 40km stretch of a diesel pipeline in order to proof that our system is capable to substantially reduce theft attempts by detecting hand and machine digging activities as well as unusual car and truck movements.

For telecommunication and data transfer purposes a single mode fiber optic cable was already buried alongside the pipeline. Eight of the twelve fibers were already being used. One of the remaining dark fibers has been used for our monitoring system. The cable jacket comprised a metal rodent protection sheet. In addiction the cable was guided through a PVC protection tube. The cable ran alongside the pipeline with a distance of 0.9 m at a depth of 1.6 m. The pipeline passed rural areas, industrial estates, highways and a railway.

We figured out that manual digging as well as machine digging causes a typical periodical pattern. According to the application requirements the analyzing software has been configured to detect periodical digging patterns and to activate an alert mode accordingly. A time limit for one minute has been set and after that the digging activity triggered red alarm and informed the operator via the GUI as shown in figure 5.

During the test phase we already successfully detect and prevent an attempt of illegal tapping. Please take a look on http://www.youtube.com/watch?v=Y6zJblR7gqw to see our system in action.

5 Conclusion

The demand for reliable and precise pipeline monitoring systems is huge. Pipeline damages, especially due to unintended third party intervention like construction work or farming constitutes a serious risk. Illegal tapping and possible acts of terrorism are becoming a growing threat particularly in emerging countries. In the last few years a lot of incidents happened with partly devastating effects for the environment, health and the pipeline operator (financial loss, reputation etc.).

With PiMON's fiber optic based monitoring solution we provide a proven technology which helps to substantially reduce the risk of third party interference.

6. References

1. Forschungsbericht 285, 2009, BAM Bundesanstalt für Materialforschung und -prüfung
2. Handelsblatt 26.10.2012
3. MICUS Management Consulting: "Short-term actions on EO market drivers: Assessment report on factors affecting demand and supply of geo-information in respect of pipeline monitoring; Analysis report - Impact of market drivers on demand and supply of EO based geo-information in respect of pipeline monitoring. Version 2.0" and „Marktpotentiale für satelliten-gestütztes Pipeline-Monitoring", p. 9.
4. Google Maps