A SMART SYSTEM FOR MONITORING OIL PIPELINE INSTALLATIONS USING FIBER OPTIC SENSORS

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ABSTRACT

Oil Pipeline installations are national infrastructures of high economic value. This makes monitoring and protection of such installations against the threat of economic saboteurs a national issue for any government. In this paper, a system for smart monitoring of oil pipeline using optical fiber cable is presented as a solution to the inadequacy of the traditional human and/or animal physical monitoring. The designed system employs fiber optic as sensor laid along the oil pipeline installation and a software that analyses the optical signal generated to determine the occurrence of threat to the installations. The smart system takes advantage of the effect of environmental phenomenon on optical signal traversing the optical fiber sensor in the automated monitoring of oil pipeline installations. On the basis of the mathematical relationship between light intensity and applied pressure, the system is able to determine (against a pre-set threshold), an attempt or the actual vandalization of oil pipeline installation.

Keywords**:** Fiber optic sensor, Oil pipeline installation, environmental monitoring.

I INTRODUCTION

last couple of decades have witnessed a steep rise in extensive research of optoelectronics and fiber optical communication.This has resulted in applications focused initially on military and aerospace equipments, health monitoring, heritage culture and various engineering fields. These developments in both optoelectronics and fiber optic communication industries are used extensively in fiber optic sensor (FOS) technology. Mutual developments have resulted in optimization of components and prices with development of high quality products to replace traditional sensors for rotation, acceleration,vibration, electric and magnetic field measurement,temperature, pressure, corrosion, crack formation, acoustics, linear and angular position, strain, humidity, viscosity, chemical measurements and a host of other sensor applications. Hence, fiber optic sensors have wide range applications in telecommunications, oil and pipeline, ships, submarines, satellites, office buildings, trains, automobiles, manufacturing plants, scientific labs, trans-oceanic communications links, aerospace, civil infrastructures, biomedical, healthcare systems and everywhere communication or data is exchanged.A fiber optic sensor is a sensor that uses optical fiber either as the sensing element or as a means of relaying signals from a sensor to the electronics that process the signals. They are ideal for harsh conditions including high vibration, extreme heat, and noisy, wet, corrosive or explosive environments. They are small enough to fit in confined areas and can be positioned precisely where needed with flexible fibers. A fiber optic sensor can be configured to measure a wide range effects via changes in light beams that are propagating through the optical fibers. It presents unique features that have no match in conventional sensing techniques. Fiber optic offers an effective and reliable monitoring system, which supports high performance sensory technology that fulfills the following characteristics below:

- Immunity to electromagnetic interference: protected from lightning strikes and electrical hazards.
- Rugged and robust: can withstand harsh environment and temperature either on or inside any component.
- Multiplexing: many fiber sensors are inter connectable. This results in extremely vast sensing network along a single fiber line.
- Multifunctional capabilities.

The above mentioned features of fiber optic sensor provides the motivation for adopting it for oil pipeline installation monitoring over other environmental monitoring technology like the Wireless sensor nodes. One of the limitations of the wireless sensor nodes, is that the environment they are usually deployed, such as oil pipeline installations are hostile. Oil pipeline installations are critical national economic infrastructures and hence are attractive targets of financial and economic criminals as well as violent or military attack in a period of war and insurgence or civil unrest. In addition to these dangers, wireless sensor nodes when deployed for such environmental monitoring as oil pipeline installations, suffer from environmental hazards and electronic danger in the form of electronic espionage and attack. Fiber optic sensor by its nature provides assurance against these known limitations of wireless sensor nodes and thus can be argued to provide a better alternative to automated oil pipeline monitoring.

Another factor that gives fiber optic sensor an edge over such environmental monitoring technology like the wireless sensor nodes, is the fact that sensor deployment are usually in remote often inaccessible places, and are expected to perform their sensory functions for a very long time, many months and at times years[1]. This a major challenge in wireless sensor nodes, because their battery power is very limited and it is not easy to replace or replenish it. However, optical fiber sensors does not have such limitation. Furthermore, while some might push the lower cost of wireless sensor nodes as an advantage over fiber optic sensors, the fact that wireless sensor node energy source needs to be replaced and at times the node itself needs to be attended too, create a maintenance cost that in the long run might nullify any economic advantage it has over fiber optics. Besides, the socio-economic and political importance of oil pipeline installations justifies any additional cost, if any, that fiber optic sensor technology might incur as a compromise for efficiency, ruggedness and reliability. In a country like Nigeria, the volume of oil products lost to vandals amounts to monumental sum of money on a daily basis. The havoc caused by spillage as a result of the activities of these vandals on aquatic life and the farm lands of those communities where the spillage occurs is an additional cause of national worry. The activities of these vandals have, regularly, been touted as major cause of scarcity of oil products that has always led to untold social and economic hardship to the populace.

This work proposed and simulated a smart system that makes use of optical fiber cable and its fiber optical- sensory technology for monitoring oil pipelines. The sensed data from the sensor(s) is transmitted in the form of optical pulses through the optical fiber cable to a computing device which, with the aid of a software, analysis and determines the occurrence, place and time of vandalization along the pipeline installation.

II RELATED WORK

Inaudi (2010), demonstrated that distributed fiber optic sensing provides unique features that conventional sensing techniques do not. The authors observed that the ability to measure temperatures and strain at different points, along a single fiber, is a perfect fit for monitoring of elongated structures like pipelines, flow lines, oil wells, and coiled tubing. They also highlighted the fact that the fiber optic sensor technology allows the monitoring of a distance of 60 km of pipeline, from a single instrument and up to 300 km, with the use of optical amplifiers. The paper also reports several field applications of this technology, including leakage detection on brine and gas pipelines, strain monitoring on gas pipelines and combined strain and temperature monitoring on composite flow lines, and composite coiled tubing pipes.

A review of the different methods used in monitoring the integrity of fuel pipeline was discussed byZhang (1996). The methods were categorically classified into three namely; Biological methods by visual inspection, involving experienced personnel and trained dogs, Hardware-based methods involving the use of hardware devices such as acoustic sensors and gas detectors, negative pressure detectors and infrared thermographs and software-based methods, which make use of computer software packages. The work reported by Stafford etal (1996), examines regulatory requirements and legislatures' on pipeline leak detection in different countries as well as the relative responsibilities of operating companies and suppliers. Annamdas (2011), classify health monitoring into two approaches; the traditional monitoring methods and the fiber optics as belonging to the finest class of smart system-based methods. In the work of Jin et al (2008), a sensor network platform for pipeline system monitoring, was presented. The authors made clear the necessity for continuous automatic monitoring systems that can provide early detection and warning on defects such as corrosion and leaks before they reach the magnitude of a major disaster. The work of Jawhar (2006), gave an overview of ad hoc sensor networks and their applications to environmental monitoring, military, ecology, agriculture, inventory control, robotics and health care. It also discusses the issues and challenges in the use of this technology, in the protection and monitoring of the critical and essential infrastructures of pipelines carrying oil, gas, water, and other important resources. The work of Newson et al (2006), shows that distributed fiber optic sensors offer unique possibilities for monitoring a wide range of variables. Their distinctive property is the ability to, spatially, resolve the environmental phenomenon, along the entire length of the sensing fiber. Further research effort towards increasing the range of distributed temperature sensors to above 50km and developing a distributed strain sensor was also proposed. Liou (2007), shows that a system response to an impulse can be used to detect and diagnose abnormalities. The impulse response can be extracted by using cross-correlations between a low amplitude pseudo random binary disturbance input and the system's output. This idea, wasproposed, for real-time non-interruptive integrity monitoring of pipeline. The feasibility of using impulse response to detect and locate a leak in real-time was demonstrated. Geiger (2006),provides an overview of methodologies, methods and techniques for leak detection. The author divided the means of monitoring leak detection in two ways; externally based systems and internally based systems.

II the fiber optic sensor smart system

The smart system involves installing optical fiber cable and its fiber optics sensory technology along with the pipeline itself (see figure 1).

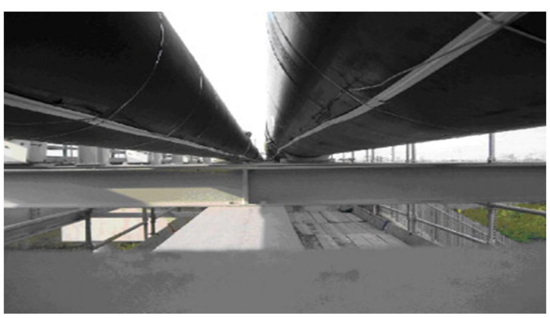

Figure 1: Optical fiber cable laid along a pipeline

The fiber optic sensors will be placed at different locations on the cable (the cable provides for real time communication and data exchange between the pipeline installations in thefield and the human monitored control room) for easy localization of the particular point where the pipeline is been vandalized. Take for instance, a pipeline that is 100km long is to be monitored, installing four (4) sensors would be sufficient enough to monitor such a pipeline. These sensors are to be at 25km intervals, in order to determine the exact point of intrusion. Thus enabling effective maintenance and repairs, reduce the wastage and loss incurred and as well act as a deterrent to vandals.

System Operation

Before going into the operational details of the proposed system, it is pertinent to establish that in optical communication, electrical signals (bit stream) are converted into light/optical pulses with the help of the light emitting diode or laser diode at one end of the communication system. This travels through the fiber optics cable, and at the other end, photo electric cells does the reverse by converting the flashes of light back to electrical signals.

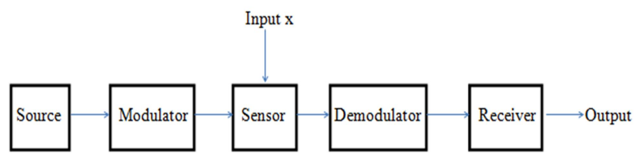

Figure 2: A fiber optic sensor system

Figure 2 shows a typical fiber optic sensor communication system. The sensor depends on the properties of the optical fiber itself to convert an environmental action into a modulation of the light beam passing through it. Here, one of the physical properties of the light beam may be in the form of frequency, phase, polarization; intensity. Our proposed smart system, for oil pipeline monitoring, will adopt the light intensity.

Intensity based fiber optic sensing technology is based on the change of transmitted power as a function of pressure/stress (Garcia et al, 2010). Hence the system is based on the change in intensity (transmitted power per unit area) to the pressure applied by vandals, attempting to vandalize the pipeline. The effect of the pressure which the intruder exerts on the pipeline has a corresponding light intensity value. If this pressure goes beyond a pre-set value, the sensor senses this and generates an alarm.

In setting the threshold pressure, the first consideration is the ideal pressure, which is the constant pressure that exists when there is pure silence, (absence of actions like tampering or alteration on the pipeline). This pressure is given as = 10^5 N/m^2. Next is the ground pressure which occurs as a result of vibrations caused by objects moving in the vicinity of the pipeline. The maximum value for this is a function of the expected vehicular and human traffic within the vicinity. Also, care must be taken to ensure that ordinary movement is not misconstrued as an attempt at vandalization by the system.

The decision as to decide if vandalization attempt has occurred is actually made by the software part of the system. The system is designed to send a signature message in the form of a predetermined binary bit sequence at specific regular intervals of, say 60 seconds. The value of sensed pressure is compared, by the application, to the threshold pressure. If the value exceeds, the threshold, the system generates a specific bit sequence and if the value is below, another bit sequence is generated. The value of bit sequence generated as a result of the pressure value is chosen so that when it is lower than the threshold, the signature or monitoring message sent at periodic intervals is un-altered and when it is higher, it alters the signature message, thus indicating a vandalization attempt.

IV. SIMULATION.

C++ programming language is used to simulate the system. For simulation of the signature message, we chose a keep-alive *HELLO* message to be sent at regular interval of 60 seconds.

a. Generating the bit Sequence

For the "Hello" The bit stream is generated by assigning values from 0 to 50 to the alphabetical letters in English language. Each letter has its corresponding number attached to it (see Table 1). The final value of the summation of all the value of the letters contained in the word is converted into binary digit, to form the bit stream of the signal.

Table1: The letters and the value assigned to them

LETTER	ASSIGNED VALUE
A	0
B	2
C	4
D	6
E	8
F	10
G	12
H	14
I	16
J	18
K	20
L	22
M	24
N	26
O	28
P	30
Q	32
R	34
S	36
T	38
U	40
V	42
W	44
X	46
Y	48
Z	50

From the table 1 above, H is assigned 14, E is assigned 8, L is assigned 22 and O is assigned 20.
To get the binary of *HELLO*, we sum 14,8,22,22,20
Therefore HELLO = 14+8+22+22+28
HELLO = 94
94 in binary = 01111110
Therefore *HELLO* in binary = 01111110

b. How the Bits Alter the Signal

As explained earlier, pressure above, below or equal to the threshold value, each, generates certain bits, correspondingly. When the applied pressure is above the threshold, the software generates binary bit 11111111, while when the applied pressure along the pipeline installation is below the threshold, the system generates 00000000. The OR logic gate is then applied to the *HELLO* bit sequence and the generated binary bits as a result of applied pressure value on the pipeline. Tables 2 and 3 shows the result of the OR gate on the signature message binary sequence and the bit generated for pressure above threshold and pressure below the threshold respectively.

Table 2: Effect of applying pressure above the Threshold

HELLO Binary Sequence	0	1	1	1	1	1	1	0
Pressure above Threshold Bits	1	1	1	1	1	1	1	1
OUTPUT	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table 3: Effect of applying pressure below the Threshold

HELLO Binary Sequence	0	1	1	1	1	1	1	0
Pressure below Threshold Bits	0	0	0	0	0	0	0	0
OUTPUT	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**

In figure 2, as a result of applying pressure above the threshold, the signature message was altered. Hence, when this happens an alarm is triggered to indicate an attempt to vandalize the pipeline. Because of the distribution of the fiber optic sensor, it will be easy to localize the point in the pipeline where the disturbance occurred. Figure 3, however indicates a situation in which the sensed pressure is below the threshold, hence the *HELLO* message remains unaltered.

In summary, when the sensors, sensed pressure around the vicinity of the installation, the value of the pressure is recorded by the system. From here, the computer program checks if the pressure applied is greater than or less than the acceptable pressure. If the pressure applied is above the threshold, a set of bit is generated, likewise if it is below the threshold, a certain amount of bit is generated. After that, it performs a logical test by OR-gating the pressure, as represented, in bits, with the bit sequence of the *HELLO* message. If the result obtained, after OR-gating, is 01111110, the HELLO binary bit has not been altered; an indication that, nothing of serious concern has occurred, otherwise, there has been an alteration, of the *HELLO* signature message, prompting the computer to display an alert of possible vandalization.

Using figure 2 above, we can put our proposed oil pipeline smart system monitoring in pictorial perspective. From the diagram, the *HELLO* message is sent from the source, serving as the first input that is transmitted over the optical fiber cable. The modulator does the necessary conversion and the signal traverses the cable. At the point where we have the sensor, a pressure is exerted on the pipeline, which is regarded as another '***input x'***. The sensor now plays its own role because it measures a physical quantity (pressure) and converts it into a signal which can be read by an observer or by an instrument. The logical operation is performed and the result is transmitted to the demodulator which does the reverse of the modulator. This result is further sent to the receiver where the output of the result is displayed.

V. CONCLUSION

This work has demonstrated how the fiber optic sensor technology can be leveraged on, in the design and implementation a smart monitoring system for oil pipeline installations. Considering the various features of fiber optic sensors, we conclude it is more suitable for environmental monitoring like oil pipeline installations. This paper has demonstrated a very basic system that can effectively help in accurate and speedy identification and localization of activities of oil pipeline vandals. The ability to give information about the exact location ofthe leakage allows an immediate reaction at the event location, minimizingdowntime and ecological consequences. This idea can be extended to monitoring for oil leakages and other environmental hazards in oil pipeline installation environment. A possible future work could also include applying Digital signal processing techniques to obtain a more complex but rugged system.

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