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PROGRAMMABLE LOGIC CONTROLLER BASED FIBRE BRAGG GRATING IN-GROUND INTRUSION DETECTION SYSTEM

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Abstract

In this paper we present an in-ground intrusion detection system for security applications. Here, an optical fibre pressure switch is directly connected to a standard digital input of a programmable logic controller (PLC). This is achieved using an intensiometric detection system, where a laser diode and Fibre Bragg Grating (FBG) are optically mismatched, resulting in a static dc offset from the transmitted and reflected optical power signals. Pressure applied to the FBG, as the intruder stepped on it, induced a wavelength shift in the FBG. The wavelength shift was then converted into an intensity change as the wavelength of the FBG matched the wavelength of the laser. The change in intensity, measured by the optical detectors, resulted in a significant change in the DC offset, behaving as on optical switch. When connected to the PLC the optical pressure switch was used to drive a digital output, sounding an alarm in addition to displaying the intrusion event on the human machine interface.

Keywords

Fibre Bragg Gratings, Intrusion Detection Systems, Optical Fibre Sensing, Pressure Switch, Programmable Logic Controller, Security

INTRODUCTION

Modern security systems are required to have inherent intelligence in order to provide diagnostics about potential and real-time security breaches. As such, most security systems nowadays use Programmable Logic Controllers (PLCs) for this intelligence (Yilmaz, 2010). PLCs are also utilised in building management systems, for controlling other building systems (eg HVAC) in addition to the intrusion detection systems (Becker et al, 2005).

In general, PLCs are used in a wide variety of industries, from factory assembly lines to controlling lifts in buildings, as well as controlling large mine sites (Kouthon and Decotignie, 1996). A PLC is an electro-mechanical computer, specifically designed to take in information from a real world processes and react to those sensing inputs in a specific way, as outlined by the control program (Bolton, 2009). For example, a PLC may receive data corresponding to the level of a liquid in a tank and then send a signal to the field to open a valve, stop a pump, sound an alarm, or any other action, depending on what is required in the application. Currently, there are a number of different communication and sensing standards, depending on the application and PLC manufacturer.

Optical fibre sensors are now used in a large variety of diverse applications, from static and dynamic strain sensing, to chemical and biological sensing (Liang et al, 2005). It is well recognised that optical fibre sensors have many desirable attributes which are advantageous with respect to other sensing methodologies. These advantages include greater sensitivity, reduced size and weight, and immunity to electromagnetic interference (Giallorenzi, 1985). Nevertheless, in general, optical fibre sensors are underutilised in security applications as simpler traditional sensing techniques are usually preferred. The use of optical fibre systems is increasing in some security applications however, for both transmission of information as well as for sensing applications, since these systems are immune to electromagnetic interference, and offer faster data transmission rates (Purpura, 2008).

Where fibre optic sensors are used in security applications, for in-ground and perimeter fence security (Regnier et al, 2009), the associated technology is quite dated, using optical time domain reflectometry (Bucaro, Dardy, and Carome, 1977) and interferometry (Barnoski and Jensen, 1976). These methods completely underutilises many of the advantages associated with modern optical fibre systems (multiplexing, reconfigurability, etc). In addition to this, current optical fibre sensing work is primarily based on optical fibre Bragg gratings (FBGs). FBG sensors were first reported by Morey, Meltz, and Glenn (1989), after demonstrating their transverse holographic fabrication method for FBGs (Meltz, Morey, and Glenn, 1998). FBG sensors have been used for the detection of number of different measurands including temperature, strain, and pressure. Initially, FBGs were used as spectral transduction elements, meaning that the information was an absolute quantity encoded on the wavelength shift of the FBG. The advantage of this technique was that the FBGs were immune to optical power fluctuations. As such, they can be implemented in Wavelength Division Multiplexing (WDM) or Time Division Multiplexing (TDM) systems (Kersey, 1994). Unfortunately, these systems require spectral decoding of the sensor signals, which can be costly and processor intensive. A more efficient alternative is to use FBGs in an intensity based edge filter detection system where the intensity information from the FBG can easily be correlated to the change in the measurand i.e. the relative spectral shift in the FBG filter results in an optical power change.

The disadvantage of intensity based detection systems is that input optical power fluctuations are reintroduced into the system. However, the simplicity of the detection method and reduced cost, since spectral decoding in not required, greatly outweigh the corresponding disadvantages in certain applications, e.g. the output of a digital intensity signal. Hence, these systems would be preferred in certain security applications (for pressure and reed switches).

Essentially, an FBG detects a change in a measurand as a result of experiencing a strain in an optical fibre, which then alters the reflected wavelength from the FBG. As such, FBGs can be used for a number of different sensing techniques. Although FBGs are predominantly used as analogue sensors, relating directly to the variation of a specific measurand, in this work we show that they can be used effectively as optical switches by shifting the Bragg wavelength. This is directly applicable to intrusion detection systems, where switches are commonly utilised, such as reed switches (Wild, Swan, and Hinckley, 2011). In this work, we show that a simple FBG switch, specifically a pressure switch, can easily be connected to an existing digital input on a commercial PLC I/O rack.

THEORY

Fibre Bragg Grating Fundamentals

A FBG (Orthonos and Kali, 1999) is a spectrally reflective component that uses the principle of Fresnel reflection. The grating is made up of alternating regions of high and low refractive indices. The periodic grating acts as a filter, reflecting a narrow wavelength range, centred about a peak wavelength. This wavelength, known as the Bragg wavelength (λ_B), is given by,

$$\lambda_B = 2n\Lambda, \tag{1}$$

where*n* is the average refractive index of the grating, and Λ is thegrating period.Equation (1) indicates that any measurand that causes either a change in the refractive index or grating period can be detected with the FBG. A change in grating period is a direct result of the applied strain, while the change in refractive index is a result of the strain-optic effect. The change in the Bragg wavelength ($\Delta\lambda_B$) as a function of applied strain (ε) is given as (Orthonos and Kali, 1999),

$$\Delta\lambda_B = \varepsilon\lambda_B\left(1 - \frac{n^2}{2}\left[p_{12} - \nu\left(p_{12} + p_{11}\right)\right]\right). \tag{2}$$

where v is Poisson's ratio, and p_{12} and p_{11} are the strain optic coefficients. Equation (2) then enables the strain applied to the grating to be converted into the shift in the wavelength, which can be easily determined via an interrogator.Any measurand that has the ability to affect either the refractive index or the grating period can be measured using an FBG as a sensor. The change in the measurand will corresponds to a change in the peak reflected wavelength. The fundamental principle of operation is shown in Figure 1.

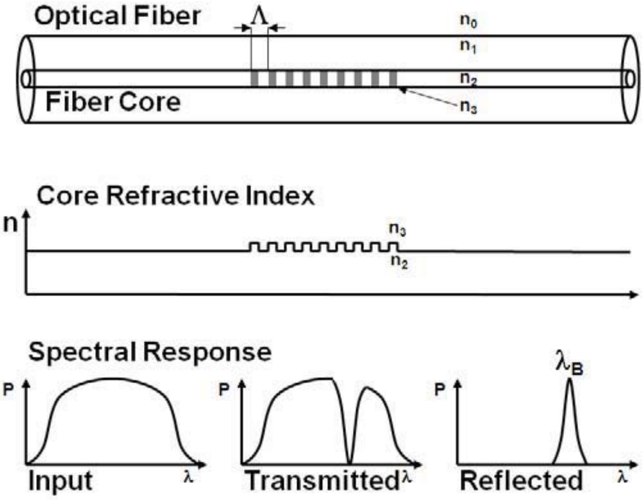

Figure 1. Fundamental principle of operation for a fibre Bragg grating.

Transmit Reflect Detection

There are essentially two broad interrogation methods available for the detection of high frequency acoustic signal with FBGs. These are edge filter detection methods, and power detection methods. In edge filter detection methods (Perez, 2001) the shift in the FBG spectrum is detected by use of a spectrally-dependent filter which results in a change in intensity at the detector. The FBG is illuminated by a broadband source, such as a super-luminescent laser diode (SLD). The change in the wavelength reflected causes the transmitted intensity to vary as the filters transmittance varies as a function of wavelength.

In power detection methods (Lee and Jeong, 2002) the shift in the FBG wavelength is detected by using a spectrally-dependent source, which results in a change of intensity at the detector. There are two power detection methods, linear edge source, and the narrow bandwidth source.

In narrow bandwidth source based power detection (Webb et al, 1996), either the reflected component or the transmitted component from the FBG can be used. However, both the transmitted and reflected components occur simultaneously. As the strain from the acoustic field varies the Bragg wavelength, the FBGs 3dB point is also shifted. As a result, the amount of optical power reflected from the FBG will change, either positive or negative, depending on which edge of the FBG was used, and the direction of the measurand. The same variation also occurs to the optical power transmitted through the grating, although in the opposite direction. Since the components vary in opposite directions, they can be differentially amplified to increase the overall signal. Figure 2 shows the optical circuit for the TRDS.

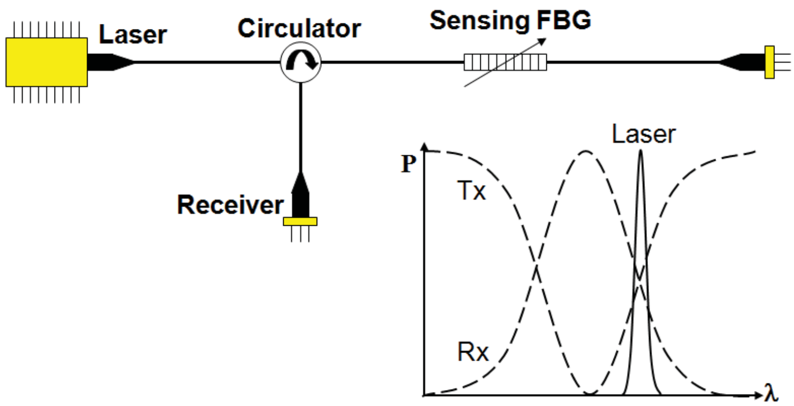

Figure 2. Optical circuit of the TRDS, with the tunable laser (TL), and the transmit (Tx) and reflect (Rx) receivers. The inset shows the spectrum of the optical components.

TRDS FBG Switch

The TRDS can be utilised as an optical switch. Here the FBG has a similar bandwidth to the laser. The laser is tuned to a wavelength just above the Bragg wavelength of the FBG. As the strain is applied to the FBG, the spectrum of the FBG will shift to match the laser. This means that the majority of the optical power of the laser, which was previously transmitted through the FBG, is now reflected from the FBG. This detection principle is depicted in Figure 3.

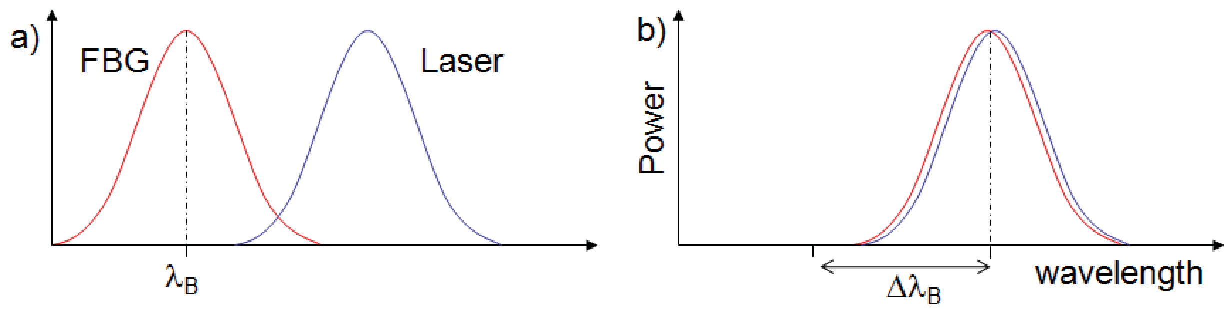

Figure 3. Operating principle of the TRDS FBG switch, a) shows the FBG offset from the laser, with no applied measurand, hence all optical power transmitted, and none reflected, b) shift in the Bragg wavelength due to the applied signal, giving maximum reflection, and minimum transmission.

The change in transmitted and reflected optical power signals was then detected using the previously reported intensiometric detection system (Wild and Hinckley, 2008), based on the Transmit Reflect Detection System (TRDS) (Wild, Jansz, and Hinckley 2007). Here the two signals were measured via two photodetectors. The reflected signal was directed to the first photoreceiver via an optical circulator, and the transmitted signal was directed straight to the second photodetector.

EXPERIMENTAL METHOD

The first step of the experiment was to characterise the spectral response of the FBG and the tunable laser. The experimental setup is show in Figure 4. This was used to determine the operating point for the FBG sensor and to ensure that the FBG and laser were mismatched by the required amount. The optical circuit uses a broadband superluminescent diode, SLD (DenseLight) as the light source to measure the FBG, and an Optical Spectrum Analyser, OSA (Anritsu MS9001B1) as the detector. The loss function of the OSA (Anritsu MS9001B1) was used to measure the spectral response of the FBG (Photronix Technologies). The OSA was also used to look at the output of the tunable laser source (Ando AQ8201-13B). The laser was tuned to be 0.2nm greater than the Bragg wavelength; the shift measured using the OSA when the pressure was applied to the FBG.

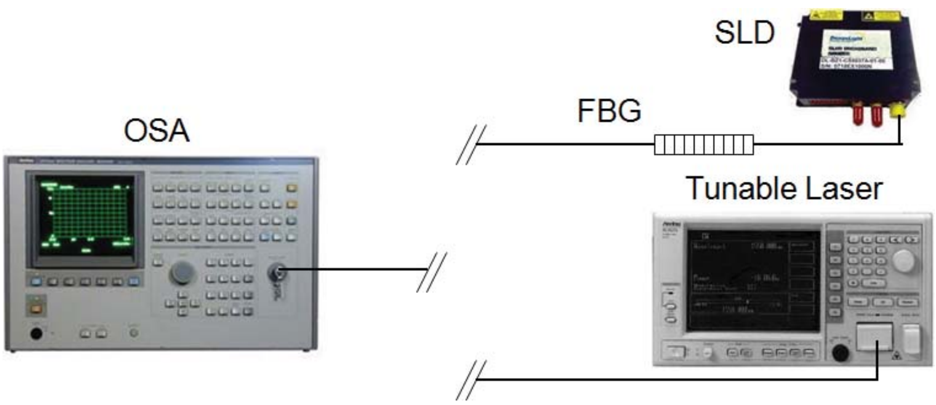

Figure 4. Experimental setup for the spectral measurements of the FBG using the SLD (top) or the tunable laser (bottom).

In the second step of the experimental procedure, the laser output was connected to a circulator (FDK YC-1100-155) so that both the transmitted and reflected signal could be detected. In order to increase the amplitude of the output signal, both outputs were connected to the detection system. In the intensiometric detection system, any change to the transmitted and reflected signals is differentially amplified, combining the two signals. The difference signal from the detection system was then amplified using a simple circuit, in order to ensure the output voltage would be correctly interpreted by the PLC, and connected to the I/O rack, as shown in Figure 5. The digital input card detects a 1 when the input voltage is above 15V and it detects a 0 when the input voltage is below 5V. The 24V is also supplied by the PLC.

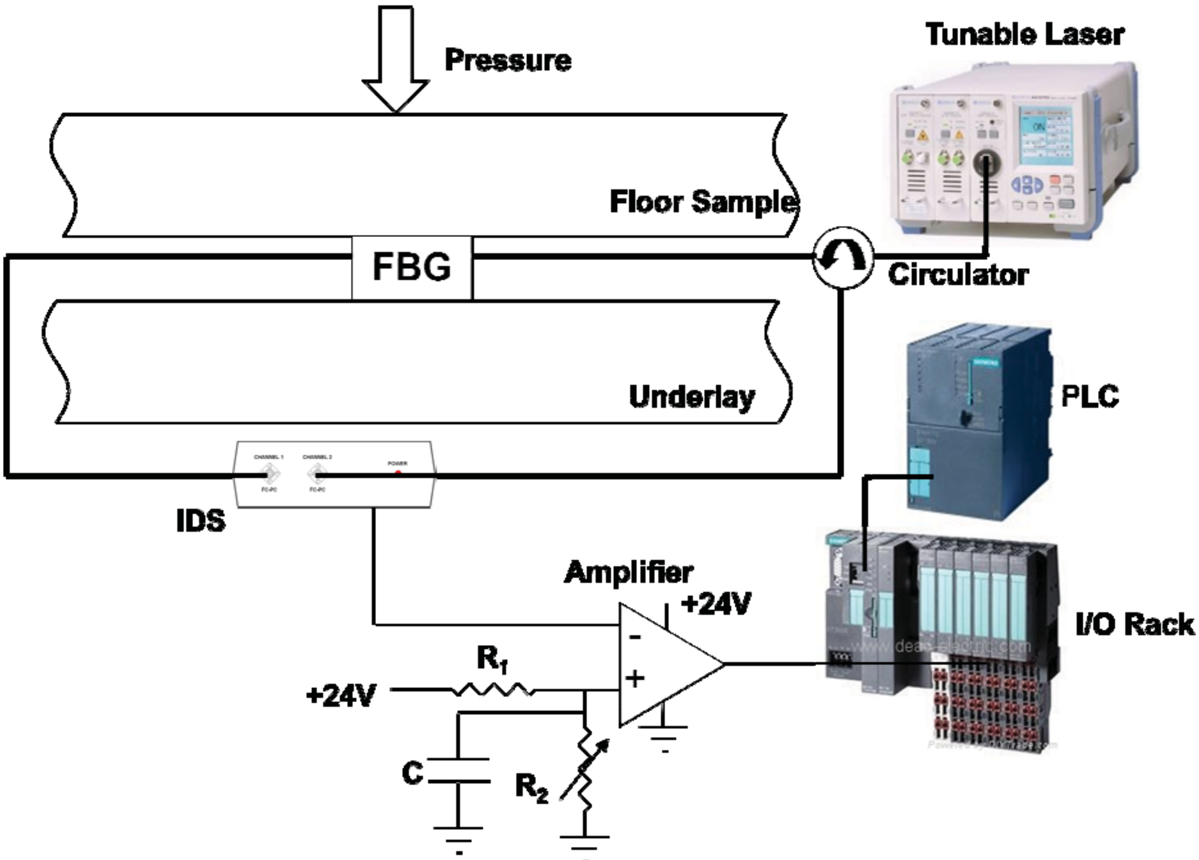

Figure 5. Experimental setup for the in-ground pressure switch connected to the PLC I/O rack.

RESULTS

As pressure was supplied to the FBG in the form of a footstep the DC voltage increased significantly as shown in Figure 6.

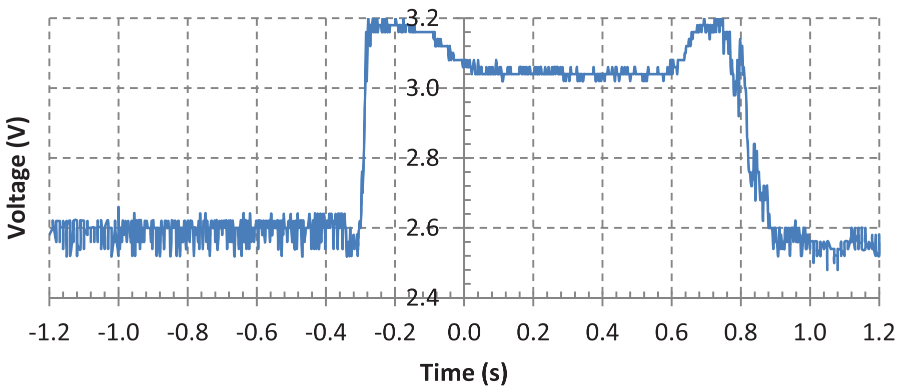

Figure 6. DC output from the FBG pressure switch as pressure is applied.

The digital input from the pressure switch was used to drive a digital output buzzer alarm using some simple logic shown in Figure 7.

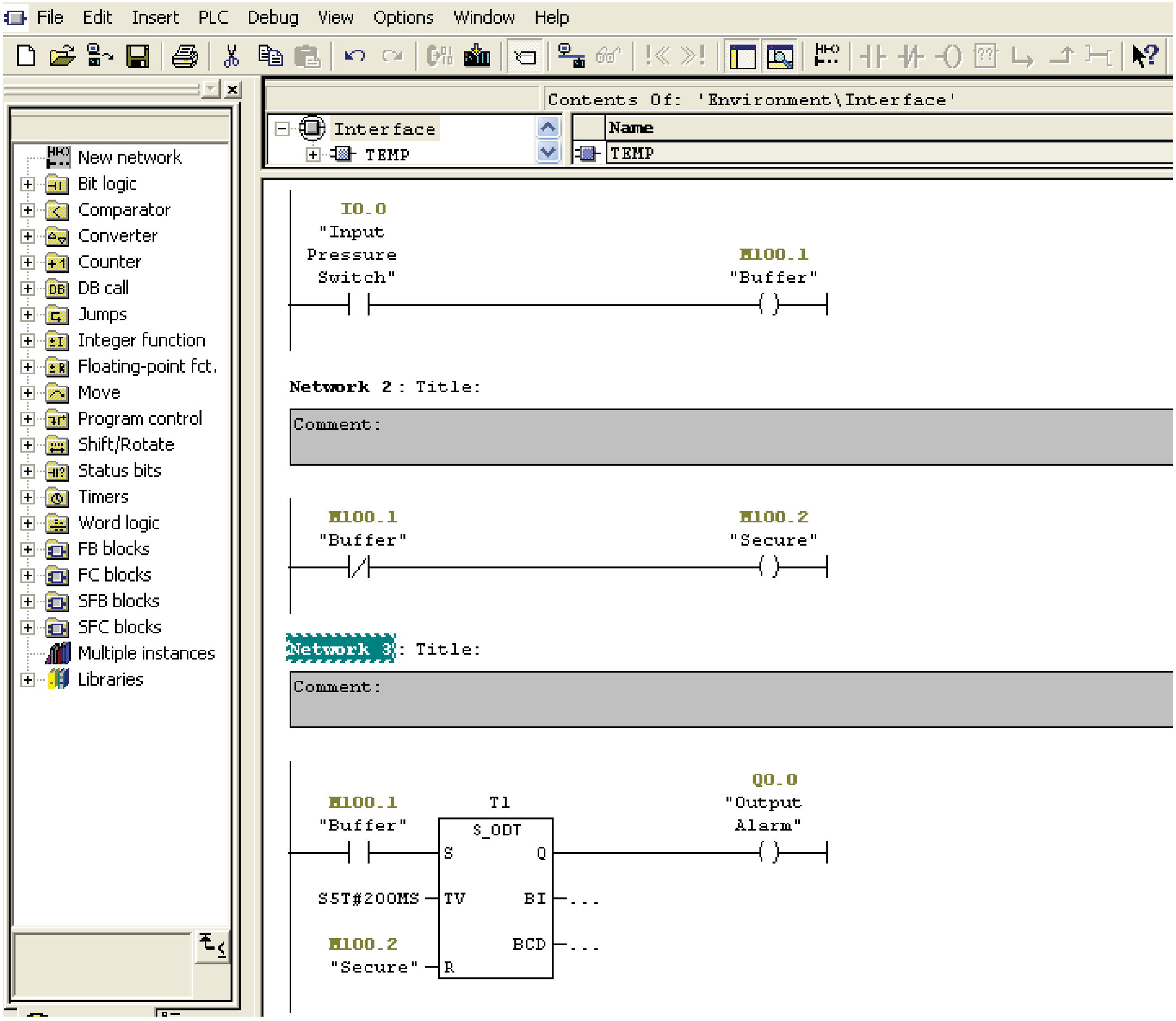

Figure 7. Simple ladder logic for turning on an alarm siren when a security breach is detected in the form of an optical fibre in-ground pressure switch.

The optical fibre in-ground pressure switch was also configured to trigger an alarm that could be display on a human machine interface (HMI) as shown in Figure 8.

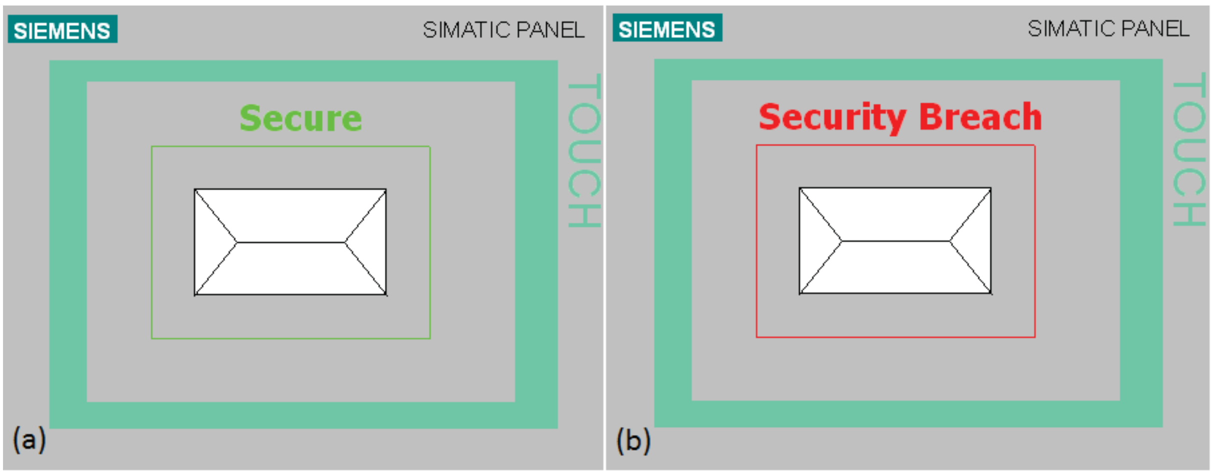

Figure 8. A simple HMI display for (a) a secure perimeter and (b) a security breach

DISCUSSION

Findings

This work shows, not only that optical FBG switches are effective and reliable, but also that they can be connected directly to an existing PLC architecture, minimising cost whilst having all of the benefits associated with optical fibre sensors, with the simplicity of digital signals. This is advantageous for security applications, where switches are used for intrusion detection. In this case we have used a FBG pressure switch, other optical switches such as a FBG reed switch could easily be connected to the PLC in the same way.

Future work

Future work will investigate the temperature cross sensitivity of FBGs. The temperature sensitivity of FBGs can cause the Bragg wavelength of the sensor to drift, stopping the switch from working. However, by using two co-located FBGs, one of these will be isolated from the applied strain, with both being exposed to identical temperatures, eliminating the temperature cross sensitivity. This will also enable wavelength division multiplexing and time division multiplexing to be easily combined, enabling large numbers of sensors to be multiplexed in a single system. This will also remove the cost associated with the use of tunable laser. The use of a single SLD will also facilitate the multiplexing of multiple switches, both pressure and reed switches.

This work is part of an extended study with the aim of producing a completely optical security system that can be implemented in both commercial and domestic environments. The aim is to use pressure switches, like the one demonstrated here, in conjunction with other innovative optical fibre sensing techniques. These include optical fibre reed switches for intrusion detection in doors and windows [Wild 2011], and FBG sensors in perimeter fences. Furthermore, analogue measurands will be detected using multiplexed FBGs embedded within the ground, forming a network that can track acoustic emissions from the footsteps of a potential intruder. The intention is to develop software that can display a person's location around a building in real time. This technology may have diverse applications outside the realm of security.

CONCLUSION

We have demonstrated an in-ground FBG pressure switch for use in intrusion detection systems. The output from the optical switch was easily connected to existing PLC architecture using the intensiometric detection system, previously reported, and a simple amplifier circuit. This study shows that conventional "wired" switches can easily be replaced with optical switches without replacing the expensive PLC hardware.

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