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In-Ground Optical Fibre Bragg Grating Pressure Switch for Security Applications

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ABSTRACT

In this study, a fibre Bragg grating (FBG) was embedded beneath three common flooring materials acting as a pressure switch for in-ground intrusion detection. This is achieved using an intensiometric detection system, where a laser diode and FBG were optically mismatched so that there was a static dc offset from the transmitted and reflected optical power signals. As pressure was applied, in the form of a footstep, a strain induced wavelength shift occurred that could then be detected by converting the wavelength shift into an intensity change. The change in intensity caused a significant change in the DC offset which behaved as on optical switch. This switch could easily be configured to trigger an alarm if required. The intention is to use the FBG sensor as an in-ground intrusion detection pressure switch to detect an intruder walking within range of the sensor. This type of intrusion detection system can be applied to both external (in soil, etc) and internal (within the foundations or flooring of the home) security systems. The results show that a person's footstep can clearly be detected through solid wood flooring, laminate flooring, and ceramic floor tiles.

Keywords: Fibre Bragg Grating, intrusion detection, in-ground sensing

1. INTRODUCTION

Almost all traditional sensing applications can now be replaced by optical fibre sensors. These include level, temperature, pressure, strain, vibration, chemical, electrical and magnetic field, rotation, and acceleration measurements, among others [1]. This transition from electrical and mechanical sensing to fibre optic sensing techniques has occurred because fibre optic sensors have many advantageous properties, including greater sensitivity, reduced size and weight, environmental ruggedness, and immunity to electromagnetic interference [2].

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 industry however, for both information transmission and more diverse sensing applications, since these systems are generally more secure than direct wire, immune to electromagnetic interference, and offer faster data transmission rates [3].

Where optical fibre sensors are used in security sensing applications, older optical fibre sensing technology, such as scattering and interferometry, are typically used. Current optical fibre sensing work is primarily based on optical fibre Bragg gratings (FBGs). FBG sensors were first reported by Morey, Melt, and Glen (1989) [4], after demonstrating their transverse holographic fabrication method for FBGs [5]. FBG sensors have been used for the detection of, temperature, strain, pressure, etc. Initially, FBGs were used as spectral transduction elements, which made them immune to optical power fluctuations, however, these systems require spectral decoding of the sensor signals, which can be costly, processor intensive, and slow. An alternative is to use FBGs in an intensity based detection system where the intensity information from the FBG can easily be correlated to the change in the measurand, as the relative spectral shift in the FBG filter results in an optical power change [6].

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 [7]. In this work we use the FBG switch to monitor pressure, in the form of an in-ground pressure switch, for intrusion detection in security systems.

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2. THEORY

2.1 Fibre Bragg Gratings

A FBG [8] is a spectrally reflective element written into the core of an optical fibre. The regular period of the grating, Λ, results in constructive interference in the reflection at a specific wavelength, called the Bragg wavelength, λ_B. The Bragg wavelength is given as

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

where n is the average refractive index of the grating. 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 [8],

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

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.

2.2 Interrogation

The shift in the Bragg wavelength can be determined by a number of methods. In this work the FBG is used as a narrow band filter, with 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 increase in the Bragg wavelength will shift the FBG response 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 1.

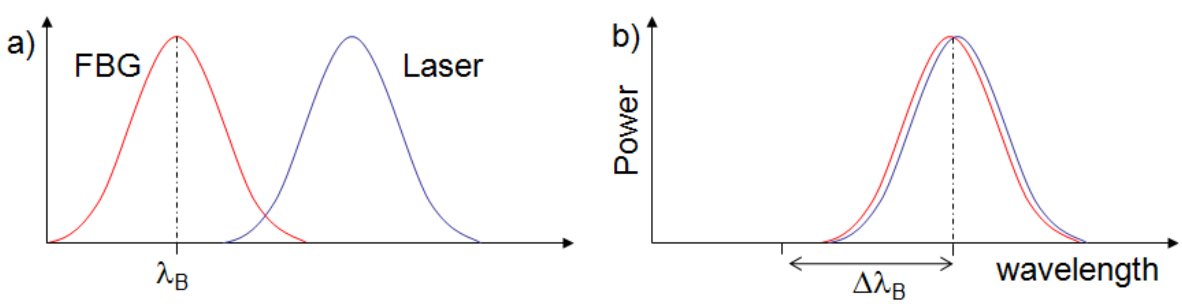

Figure 1. Interrogation principle of FBG switch, showing (a) optically mismatched FBG and laser with no applied measurand, then (b) the shifting of the FBG to match the laser when the measurand is applied.

The change in transmitted and reflected optical power signals was then detected using the previously reported Intensiometric Detection System (IDS) [9], based on the Transmit Reflect Detection System (TRDS) [10]. 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.

3. 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 2 (a). 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) as the light source to measure the FBG, and an Optical Spectrum Analyser (OSA) 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.

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 IDS. In the IDS, any change to the transmitted and reflected signals is differentially amplified, combining the two signals. The difference signal from the IDS was connected to a digital storage oscilloscope (Agilent DSO3062A) to view the change in signal, which was in turn connected to a PC for transferring the data, as shown in Figure 2 (b).

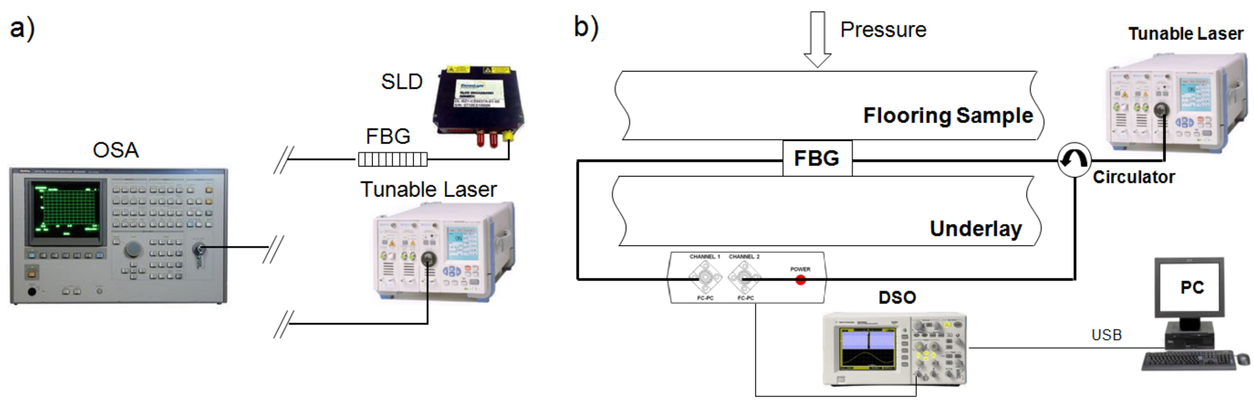

Figure 2. Experimental setup, (a) for the spectral characterisation of the FBG and the tunable laser, and (b) the in-ground pressure switch measurements.

In the FBG switch experiments, the grating was placed between a piece of underlay and various flooring materials; a piece of solid wood flooring, a piece of laminate flooring, and a ceramic floor tile. A standard footstep test was performed, where a 60kg man wearing a common soft soled shoe, walked across the sample, stepping on to the sample with one foot. This was repeated for each of the three flooring samples.

4. RESULTS

Figures 3 to 5 show the DC switching signals of the FBG beneath a piece of solid wooden flooring, a piece of laminate flooring and a ceramic floor tile, respectively. The results all show relatively strong signals, with significant signal to noise ratios. There is also a significant and steady increase from the minimum voltage (2.5V) to the maximum voltage (3V). This means that combining these signals with something like a simple comparator will enable them to be readily utilised as in-ground pressure switches. The value of the gain and the DC offset in the IDS could also be adjusted to give an electrical signal difference that is even greater. Finally, the signals also have a significant temporal response. That is, the signals last 0.8 seconds of the step. This shows that the relationship between the FBG and the laser is ideal.

The results clearly show a significant increase in the DC offset when pressure is applied to each type of flooring. This FBG switch embedded beneath the flooring could easily be configured to trigger an alarm. This type of intrusion detection system has all of the advantages of other optical security sensors, such as infra-red (IR) trip “wires”, but is also completely hidden and cannot be seen by indirect methods (such as an IR camera), as it is embedded within the floor itself.

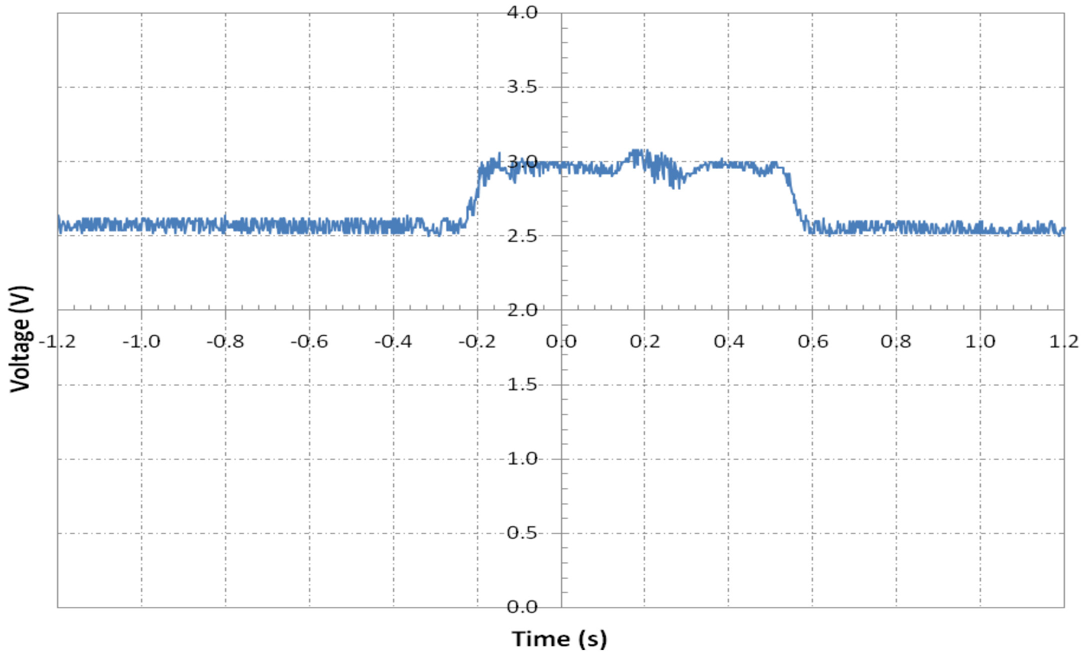

Figure 3. In-ground FBG pressure switch signal for solid wood flooring.

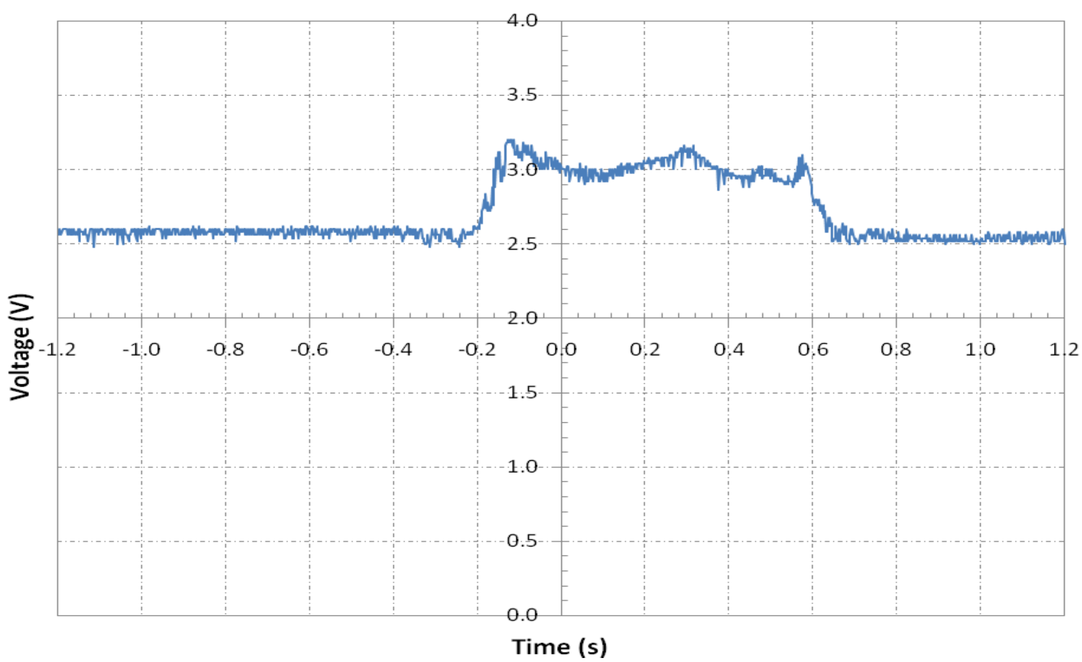

Figure 4. In-ground FBG pressure switch signal for laminate wood flooring.

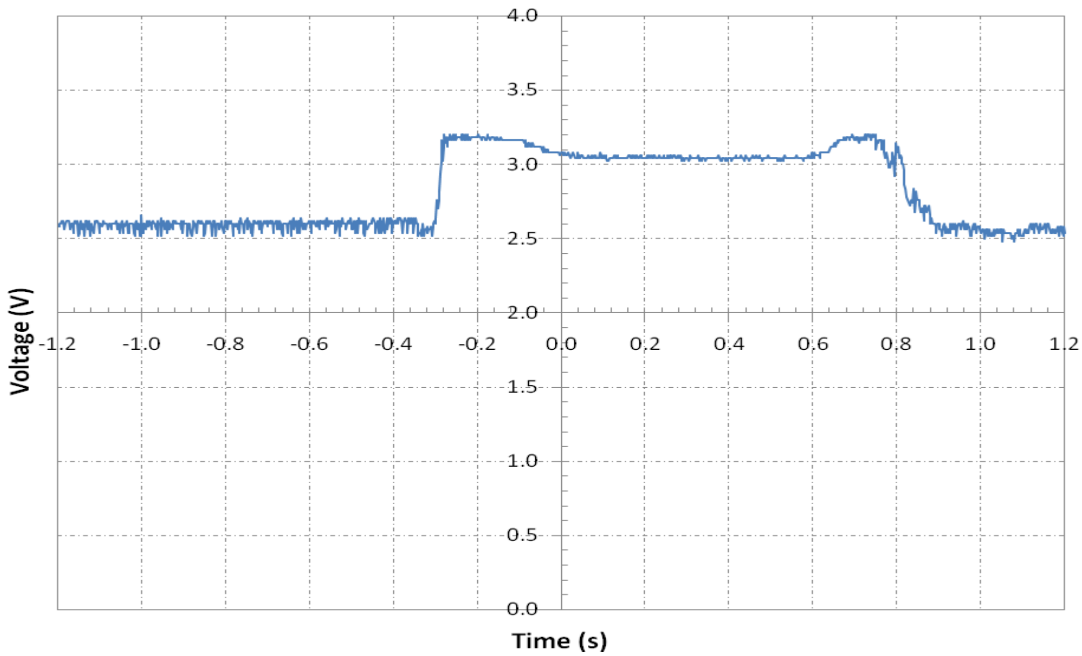

Figure 5. In-ground FBG pressure switch signal for ceramic floor tile.

5. FUTURE WORK

Here, we have not addressed the temperature sensitivity of the FBG. This will be overcome by using two co-located FBGs, one of these will be isolated from the applied strain, with both being exposed to identical temperatures. This will 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 pressure 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 [11], 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.

6. CONCLUSION

In conclusion, we have successfully demonstrated the use of an FBG switch for in-ground intrusion detection. The FBG switch is sensitive to the applied transverse pressure of a footstep located over the FBG. The intrusion detection system uses a tunable laser that was optically mismatched to the FBG. The optical power that was transmitted and reflected relative to the FBG was measured using the IDS, based on differentially amplifying the signals from two photodetectors. The FBG sensor in the samples, gave significant DC signals with the application of the measurand, making them ideal switches.

REFERENCES

[1] Udd, E., [Fiber Optic Sensors An Introduction for Engineers and Scientists], Wiley (2006).

[2] Rao, Y. J., "In-fibre Bragg grating sensors," Measurement Science and Technology 8(4), 355-375 (1997).

[3] Purpura, P., [Security and Loss Prevention: An Introduction 5th ed.] Butterworth Heinemann (2008).

[4] Morey, W., Meltz, G., and Glenn, W., "Fiber optic Bragg grating sensors," Proc SPIE 1169 98-107 (1989).

[5] Meltz, G., Morey, W.W., and Glenn, W.H., "Formation of Bragg gratings in optical fibers by a transverse holographic method," Optical Letters 14(15), 823-827 (1998).

[6] Lee, B., and Jeong, Y., "Interrogation techniques for fiber grating sensors and the theory of fiber gratings", in [Fiber Optic Sensors], Marcel Dekker, 295-381 (2002).

[7] Garcia, M.L., [The Design and Evaluation of Physical Protection Systems 2nd ed.], Butterworth Heinemann (2008).

[8] Othonos, A., and Kalli, K., [Fiber Bragg Gratings], Artech House (1999).

[9] Wild, G., and Hinckley, S., "An intensiometric detection system for fibre Bragg grating sensors", Proc. ACOFT (2008).

[10] Wild, G., Jansz, P., and Hinckley, S., "A transmit reflect detection system for fiber Bragg grating photonic sensors," Proc. SPIE 6801, 68010N (2007).

[11] Wild, G., Swan, G., and Hinckley, S., "A fibre Bragg grating based reed switch for intrusion detection," Proc. IQEC/CLEO Pacific Rim Conference (2011).