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An optical fiber intrusion detection system for railway security

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ABSTRACT

In this paper, we report the in-field demonstration of an intrusion detection system implemented using Fiber Bragg Grating (FBG) sensors. The system is conceived to protect the perimeter of an area from unauthorized accesses to railways assets. As a case study, we installed and tested the system in a real scenario, and several field trials were performed to validate the system's ability to recognize any human intrusion within the protected area. The proposed sensing system is a powerful tool to detect intruders, especially in real scenarios where protection fences are not practicable. The proposed intrusion detection system represents a valuable solution to improve railway security.

1. Introduction

In the 21st century, railways are as vulnerable as airports and government buildings to vandalism and terrorism. Transport operators have growing concerns about the safety and security of railway facilities, workers, and passengers [1].

The peculiarities of railway environments make many conventional solutions to protect them impractical. A railway asset – such as a service area, a depot for trains or a railway station – cannot be closed with barriers because they would obstruct the passage of authorized staff or passengers. An additional difficulty arises from the protection of access to rail tracks that cannot be physically obstructed by commercial intrusion detection systems such as sensorized fences or taut wire sensors. Additionally, electronics-based technologies, such as microwave sensors, electric field sensors, ported coaxial cables, and infrared sensors, suffer from electromagnetic interferences associated with train transit.

Over the past few years, to meet the growing demand for improved security, worldwide research on intrusion detection sensing systems has grown significantly [2].

Commercially available unattended ground sensor (UGS) systems make use of several sensing modalities (e.g., acoustic, seismic, passive infrared, magnetic, electrostatic, and video). The efficacy of UGS systems is often limited by high false alarm rates, and attempts to reduce false alarms could decrease the probability of detection [3,4]. As the false alarms are typically associated with the typology of the transduction principle, sensing solutions based on multiple technologies for intrusion detection offer benefits over a single technology approach in terms of their robustness and reliability [5,6]. Most modern intrusion detection systems employ multiple intrusion sensors to maximize their trustworthiness [7] because the usage of multiple technologies for intrusion detection reduces the false alarm rate while simultaneously improving the probability of detection [8–11].

A number of researchers have demonstrated that multiple sensing technologies offer information redundancy, reliability and complementarity. Lester et al. [12] show that dual technology sensors (i.e., passive infrared and microwave sensors) offer superior intruder detection and better performance for rejecting false/nuisance alarms than do single-technology systems. Similarly, to improve the performance of a system for personnel identification, Huang et al. [13] proposed a multi-sensor system based on ultrasonic, seismic and acoustic sensors to reduce the number of false alarms. To date, there are also several solutions involving visual content analysis [14–16]. Ngoc et al. [14,15] proposed a video and a multiple-sensors platform to detect and classify mobile objects. J.L. Castro et al. [16] proposed an intelligent surveillance system for the identification of dangerous intrusions based on information from video, audio and sensors.

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Despite the necessity of using several solutions based on different technologies, there is still minimal literature available regarding the use of optical fiber sensing technologies for intrusion detection [17]. Nonetheless, compared to conventional technologies, optical fiber sensing technology is potentially well suited for protecting large areas from unauthorized access.

Additionally, optical fibers are ideal for use in railway areas due to the intrinsic advantages associated with their use, such as their immunity to electromagnetic interference, high sensitivity, compactness, remote sensing ability and stability in harsh environments.

Allwood et al. [17] have recently reviewed the fiber optic techniques used in physical intrusion detection systems. They envisaged fundamentally three optical fiber technological approaches: interferometry, scattering and Fiber Bragg Gratings (FBGs) based detection.

Interferometric approaches (ranging from classical Sagnac, Michelson or Mach-Zehnder interferometric schemes [17,18] up to speckle pattern configurations [19–21]) are able to offer high sensitivities but they are also extremely sensitive to external factors such as ambient conditions. An extensive signal processing is thus continuously required to remove external noise caused by the environment.

Optical fiber scattering techniques have been also proposed for distributed sensing [22,23]. Such techniques demonstrated to be well suited for large distances, where the costs of the interrogation equipment are depreciated on the distance.

FBG-based systems have already been used in security applications for monitoring entry points such as windows and doors [24] or in fence perimeter systems [25]. FBG sensors, indeed, offer high multiplexing capability, versatility, and simplicity of use, allowing the deployment of a cost-effective interrogation strategy [26,27]. Furthermore, FBG sensors have the potential to form a complete security system based entirely on fiber optic technology. Wide functionalities can be included in a single system based on the same core technology ranging from intrusion detection up to smart diagnostics in various railway applications such as switch monitoring, axle counting, weighing in motion, and wheel flat detection [28–30].

In our previous work [27,31,32], we also demonstrated using in-lab trials that a technological solution based on FBG strain sensors is potentially able to detect human intrusions through a perimeter.

In particular, we proposed a sensorized mat composed of a ribbed rubber mat with a low Young modulus integrated with FBGs [27]. The experimental analysis was focused on the characterization of the elastic response of the sensorized mat in the presence of applied static loads to evaluate the mat's sensitivity curve, response times, and required number of sensors per unit area. Based on the results, we fabricated a mat as large as 2 m^2 with eight FBGs, and we then verified in lab the functionality of the system in the presence of intruders walking on the mat. The small-scale system also allowed for the development of a simple signal processing strategy to neglect the effects of elastic hysteresis and of thermal drifts, affecting the response of the FBGs bonded to the mat.

In this paper, expanding on the results of the previous in-lab activity, we report on the demonstration of an optical fiber intrusion detection system in a real railway scenario. Specifically, we installed and tested a sensorized rubber mat over a large square of approximately 20 m^2 at the entrance (shown in Fig. 1) of the service area of Ente Autonomo Volturno (EAV) Railway in Naples (Italy).

The sensing system is intended to be used in combination with a television close circuit (TVCC) system. As previously mentioned, the use of multiple sensing technologies offers information redundancy and complementarity. In this specific case, the TVCC system is used to cover both the access on the rail tracks and access to the "walkable" area, while the optical fiber intrusion detection system is used to protect the "walkable" area.

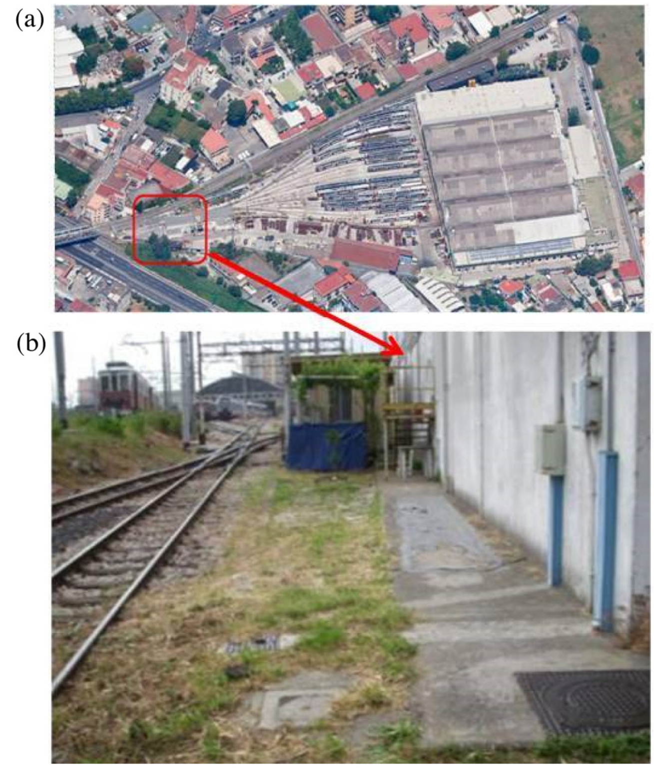

Fig. 1. Ponticelli Service Area of Ente Autonomo Volturno Railway Naples, Italy (a); service area in Ponticelli – Napoli (b).

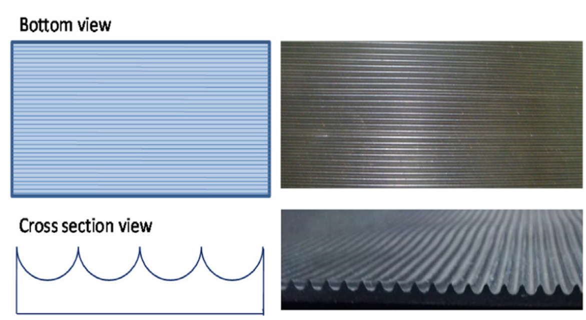

Fig. 2. Schematics and pictures of the lower surface of the rubber mat.

In the following section, we briefly describe the architecture of the intrusion detection system. In section III, we report on the system installation and on the hardware/software setup. In the fourth section, we show the experimental results obtained during the on-field tests performed at the service area in Ponticelli. Finally, the paper ends with a conclusion section.

2. System architecture

The sensing system is composed of a rubber mat with FBG strain sensors integrated on the lower surface of the mat. The sensorized mat is a scaled-up version of the prototype already demonstrated in reference [27]. Here, we briefly recall the structure of the sensorized mat and its principles of operation for the sake of completeness.

The rubber mat has a smooth upper surface and a ribbed lower surface as shown in Fig. 2. The FBGs are bonded within the ribs of the lower surface to minimize the possibility of damage to or breakage of the optical fiber.