4.6 OPTICAL SENSING AND SELF-LEARNING APPROACH TO ESTIMATE THE STATE CONDITION OF RAILWAY INFRASTRUCTURE SUBLAYERS

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ABSTRACT

The objective pursued is the implementation of a technique for intensive information capture of the state of the deep layers of the infrastructure of transport linear works, in order to (a) detect faults, (b) predict the evolution of the state as a function of time, (c) estimate the necessary maintenance operations, and (d) plan the required interventions. All this is focused on achieving greater efficiency in the management of the conservation of this kind of infrastructure. The data obtained in real time correspond to the tests carried out on a substructure section model housed in a scaled sublayer's test-rig with installed Fiber Bragg Grating (FBG) optical sensors. Finally, the methodology is described, based on data analytics and Machine Learning techniques, in order to infer the severity of measured deformations and failures.

INTRODUCTION

A significative share of transport infrastructures is composed of linear assets, such as roads and rail tracks. The social and economic relevance of these constructions force the stakeholders to ensure a prolonged health/durability, but inevitable malfunctioning, breaking down, and out-of-service periods arise during their life cycle. Of all assets that make up an infrastructure, a very relevant asset is the set of sublayers. The failure or deterioration state condition of the deep layers absorbs high levels of economic resources and generates important social impacts.

Predictive techniques tend to diminish the appearance of unpredicted failures and the execution of needed corrective interventions. The use of historical asset conditions and their corresponding maintenance interventions data, and data analytical approaches facilitate the envisaging of the adequate maintenance interventions to be conducted before failures show up.

This paper presents (i) a technological approach to capture, in real time, the stress–strain state of the infrastructure deep sublayers using optical sensing based on FBG technology, (ii) an approach to infer the state condition of the layers using data analytics, and (iii) an automatic learning procedure based on self-learning rules from automatic learning from false positive/negatives.

STATE OF THE ART

The detection of maintenance alerts is generally based on the inspection of the state of the assets through the visualization/auscultation/measurement of the explanatory characteristics of the involved asset. The evolution of these characteristics, estimated quantitatively or qualitatively, using projection techniques (i.e., regression) or qualitative (e.g., experience), and cross-checking with thresholds and limits (defined by technical standards prescribed by either the administration or infrastructure regulator), has been the main tool to anticipate possible failures or deficiencies in the operation of assets.

For decades, the inference of deterministic or probabilistic models based on a priori explanatory characteristics (i.e., empirical-mechanistic models) has been the most pronounced trend (1960–1990). Currently, developments have focused on replacing this way of proceeding by data-based modeling, making use of data mining and Machine Learning techniques (1990–2015); this is based on the increasing availability of data captured from activities, auscultations, and monitoring campaigns.

In the field of transport infrastructures, since the 1990s, the trend has focused on predicting the evolution of the state of certain components using ML techniques and data analytics; however, in most cases, attention has been focused on the prediction of easily accessible active associated indices (pavement on highways, rails and ballast on railways) or to the global state of the infrastructure using data from external geometry (1995–2020). In relation to the estimation of maintenance interventions, there have also been important advances referenced in various publications on the state of the art on this subject.

In the field of monitoring the state of deep layers of the substructure, advances have been more limited due to the cost and difficulty of sensorization. This study advances the use of data-harvesting methodologies to capture the state of the substructure at deep levels based on optical sensorization techniques and its subsequent treatment to characterize the state of integrity.

These data, properly processed, constitute an important source of information to infer the state of the substructure. The application of some techniques developed by the research team, for the exploitation of data associated with the surface assets of road networks and railway lines (Morales et al., 2017, 2018, 2020; Reyes, 2018) is at the background of this communication.

CONTRIBUTION

The contribution of the research hovers on three pillars: (a) to build and sensorize a test-rig to generate and harvest data from infrastructure sublayers, (b) to exploit the harvested data to infer a cause-effect (loading-failure) relationship using data analytics and automatic learning techniques, (c) to apply the prediction methodology derived by the research group to estimate maintenance interventions.

a) *Testing Rig*

At this stage of the project, a first test-rig scaled 1:7 has been built to simulate the condition of the infrastructure sublayers of a railway track section. The section is made of several layers of sand and gravel with embedded thin monitoring metal plates (0.25 and 0.1 m^2), between layers.

The monitoring plates house strain and temperature sensing (10 sensors each) based on Bragg Grating sensing (FBG). An eternal read-out system (interrogator), connected to the plates using silica-glass fibers, injects optical signals of modulated laser pulse-lights that interact with the sensors and that are altered by the strain suffered by the sensors when some perturbation occurs.

The FBG sensing system is characterized by its high sensitivity to any alteration either on the loadings, experienced by the track model on the infrastructure surface, or on faults appearing inside the layers.

In order to quantify the sensitivity of the substructure model, due to internal failures, a set of air pressurized cushions (with externally controlled pressure) are set inside some of the layers to artificially generate faults under several conditions.

By crossing out the level of interaction detected by the interrogator system, spatial mapping of the strain distribution inside the layers is generated and translated to soil displacements (i.e., breaks, glides, settlements). Similar tests are performed under variable loadings affecting the track surface in order to characterize the FBG sensing capability.

A second test-rig 1:1 is in process of construction, which holds a full real track section (rail, ties, ballast, sub-ballast, sublayers), with a more extensive sensorization level.

b) *Data Generation and Exploitation*

A multiplicity of tests is performed in order to generate a rich database. The tests should always be performed under variable settings (i.e., surface loadings, layers faults). The distributed strain measurements of the sensor chain array, provided by the interrogator, have to be post-processed first to map data to a free-fault condition of the layers. The second step consists in correlating/matching sensor data with the loadings and faults. The third step applies a set of Machine Learning methodologies to infer an estimating frame cause-effect. Details about this last step can be found in the references (Morales et al., 2018, 2020).

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