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Strategies of anomalies detection in bridges and tunnels as a tool for structural health management

New approaches and AI support

By

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Abstract

The control of structural condition of civil infrastructure facilities, such as bridges and tunnels, is crucial to ensure safety and to shun grave waste of economic resources. The consequences of their degradation could have a substantial impact given the crucial role that them play in the nowadays society. The development of Structural Health Monitoring (*SHM*) strategies, aimed at identifying, localizing, and estimating the severity of potential damages for a successful decision-making process in infrastructures maintenance management, has become a research topic in the last twenty years. Significant resources have been allocated, mainly in developed countries, where the infrastructure assets are composed of facilities nearing the end of their useful life and, as a result, require more attention due to aging. Nowadays, advanced studies, exploiting even highly sophisticated artificial intelligence algorithms, have been carried out to structural conditions assessment. However, many issues need to be still addressed due to the difficulty of integrating expertise from many engineering sectors and achieving rigorous validation methodologies on real-world case studies.

This thesis aims at designing and validating methodologies for the control of large-scale infrastructures, considering the features and issues of the typology to which they belong, to obtain reliable information about the current structural state and predict its evolution.

Several methodologies have been devised based on infrastructural typology, construction material, and static scheme. Such features are directly related to the structural response and to specific issues that need customized strategies to be successfully coped. The analyses, involving both numerical simulations and real case studies, have been based on several data types (e.g., static and/or dynamic parameters, images) and different monitoring typologies (i.e., continuous or periodic monitoring). In detail, customized strategies have been drawn for highway tunnels and for bridges belonging to three service classes (highway, railway, and pedestrian).

As regard the tunnel, a multi-level assessment strategy has been proposed. It exploits the high capacity of Convolutional Neural Networks (*CNNs*) to classify potential damages. Ground Penetrating Radar (*GPR*) profiles and the associated structural phenomena have been used as input and output to train and test such networks. Image-based analysis and integrative investigations have been leveraged to define the structural conditions linked to *GPR* profiles and to generate the database. The degree of detail and attained accuracy are high. As a result, this method is useful to reduce the amount and invasiveness of testing, as well as the time and cost associated with highly qualified technicians.

As regard the bridges, unsupervised and supervised approaches have been applied. As concerns the structural condition assessment of an arch highway steel bridge, methodologies mainly based on dynamic behavior have been devised and a clustering based approach has been proposed as artificial intelligence (*AI*) support. On the other hand, plans for control of simply supported prestressed concrete railway bridges have been drawn up by means of two anomaly detection methodologies developed to be complementary and economically sustainable. The first, designed for a continuous control over time, is based on regression correlation models exploting supervised algorithm; the second, devised for a periodic control, combines the use of influence lines, genetic algorithm, and neural network. Further efforts have been made to validate strategies, based on transfer learning concept, suitable for the evaluation of bridge structure which are structural similar and replicated extensively, like pedestrian bridges in high-density cities.

The use of machine learning algorithms turned out to be of paramount importance to support all the proposed approaches to obtain highly accurate and automated solutions.