Doctoral Dissertation
Doctoral Program in Civil and Environmental Engineering (32.th cycle)

Structural Health Monitoring Framework for Automatic Damage Detection based on IoT and Big Data Analytics

Application to a network of structures

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March 31, 2020

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Turin, March 31, 2020

Summary

Civil infrastructure facilities, such as bridges and tunnels, have a considerable impact on the economic, social and political growth of nowadays society. Such structural systems, due to their inherent vulnerability, may be affected by aging and degradation processes over time, which lead to a loss of the expected performances.

Structural Health Monitoring (SHM) has assumed a key role in the past two decades in the management of important civil infrastructures, since it could provide, on a continuous real-time basis, relevant information about the behavior of critical structures, recognizing unsafe conditions and predicting potential failures.

Nowadays, several techniques are available for recognizing damages in civil engineering structures, identifying any change in the intrinsic dynamic characteristics of a system. Indeed, a large number of damage identification algorithms have been developed over the years, from the simplest to the most sophisticated, capable of identifying even very small variations in the dynamic behavior of structures.

However, in most cases, the available techniques have been tested and applied to numerical case studies or, at best, to small structures with a limited number of devices. Moreover, no methodology has been developed to cope with the most critical aspects related to the need of monitoring a large number of structures, equipped with many sensors, and providing at the same time a monitoring service for reporting in real-time any anomaly in an automatic but reliable way.

This dissertation aims at providing a new methodology for the continuous and automatic monitoring of a large number of structures instrumented with many sensors, overcoming many of the issues related to the application and management of widespread monitoring systems. More in detail, this work has focused on the development and implementation of a data-based multi-level processing framework, adequate to extract relevant information about the behaviour of structures from continuous and long-term monitoring systems and automatically generate early-stage system health indicators without any detailed analysis of the monitored infrastructure. Furthermore, the multi-level approach, based on different levels of complexity, allows avoiding high computational costs and time while ensuring a robust and reliable damage detection service.

A numerical case study has been used for selecting the most reliable identification algorithm to be implemented in the monitoring framework. Afterwards, the robustness, reliability and efficiency of the proposed methodology have been validated through real case studies. Indeed, the multi-level approach has been applied for the long-term real-time monitoring of a significant number of structures under normal operating conditions. In particular, the implemented monitoring methodology was tested thanks to real damage scenarios occurred on two of the currently monitored structures. The first case study is a box composite highway bridge, strengthened by both internal and external prestressing, where all the features of the proposed methodology were applied and permitted to detect real damages occurred during the monitoring period. The second case study is a pre-stressed concrete bridge from the early 1965s, where real changes in structural stiffness were identified through the dynamic monitoring system in which the proposed methodology has been adopted.

The two significant case studies permitted to demonstrate both the usefulness and robustness of all the components included in the proposed methodology as well as the main advantages of the developed monitoring framework. The multilevel and data-driven method was in fact able to automatically generate system health indicators (effectively detecting structural damages) without any specific analysis on the monitored structures. Damage identification algorithms were combined with statistical analysis and machine learning approaches for detecting anomalous structural behaviours while avoiding high computational cost and time.

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