Ph.D. Thesis Summary

Thesis Title:

Machine Learning Perspectives in Structural Health Monitoring

From traditional operational modal analysis to intelligent-based methods

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The term Structural Health Monitoring (SHM) identifies all those activities aimed at periodically inspecting the health status of a structural system over time in operating conditions. In particular, operational modal analysis (OMA) identifies all those techniques based on the analysis of output-only vibrational responses during in-service situations without measuring the input excitation. The main goal of OMA is to determine the modal properties, i.e. natural frequencies, damping ratios, and mode shapes of a structure. These parameters define the dynamics of the so-called combined system, i.e. comprising both the actual structural system and the loading system, this latter typically conceived as a stationary white noise excitation. The current Thesis document summarizes the research activities conducted during the current Ph.D. program mainly focused on SHM vibration-based approaches improved by innovative machine learning (ML) techniques. The mathematical framework at the base of OMA has been initially reviewed, exploring both time-domain and frequency-domain methods, and differentiating between parametric and nonparametric procedures. The PyOMA software was developed with a fruitful collaboration with two other institutions. PyOMA represented the first Python-based open-source package collecting a suite of the most used and well-established conventional OMA methods, thus deliv-

ering an essential tool for both researchers and practitioners working in this sector. Furthermore, due to the growing demand for automatic and continuous SHM monitoring systems, a novel framework named intelligent automatic operational modal analysis (i-AOMA) has been developed by leveraging the potentialities offered by nowadays artificial intelligence (AI) solutions. The i-AOMA method combines quasi-Monte Carlo sampling to reduce the impacts of the user's arbitrary choice of OMA control parameters, and postprocessing the identification results with effective ML-based data-driven solutions. This methodology can reliably identify actual physical recurrent modal properties whilst discarding those spurious ones. Moreover, it also provides an uncertainty evaluation of the modal parameter results. Generally speaking, an ideal SHM paradigm can be formalized at least into 5 levels, depending on the depth of investigation and understanding of any occurring structural damage. Therefore, the main research efforts have been herein devoted to the purpose of integrating ML innovative data-driven procedures into the SHM Level 1, i.e. referred to as the damage detection task. This is a crucial aspect because it determines the amount of economic and time resources to be earmarked for further deeper damage diagnosis and/or prognosis evaluations, and even for optimizing and prioritizing maintenance activities and safety restoration interventions. Nondestructive testing (NDT) procedures have been herein effectively integrated with deep learning (DL) methods, e.g. focusing on computer vision automatic classification of tunnel linings defects based on ground penetrating radar (GPR) surveys. Vibration-based NDT for damage detection tasks has been also analyzed, especially focusing on subspace-based damage-sensitive features derived from the mathematical framework of the OMA stochastic subspace identification (SSI) algorithm. Several research efforts should be still spent to provide further deeper insights into the above-mentioned aspects. Moreover, since the scope of applicability of conventional OMA approaches is limited to linear structures under operational stationary white noise excitation, future promising research paths should additionally explore the field of nonlinear and nonstationary OMA methods. This means exploring the methods of the actual procedure for analyzing time-varying evolving modal parameter histories computed from vibration responses of structures under transient loads, e.g. under earthquake excitation, and potentially damaging over time.