Inference and Uncertainty Quantification in Structural Health Monitoring

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Health monitoring is an essential functionality for smart and sustainable infrastructures that helps improving their safety and life span. A major element of such functionality is statistical inference and decision making which aims for processing the vibrational response of structures in order to localize the defects in those systems as well as quantifying the uncertainties associated with such predictions. Accomplishing this task requires dealing with special constraints, in addition to the general challenges of inference problems, which are imposed by the uniqueness and size of civil infrastructures. These constraints involve the small size and high dimensionality of the relevant data sets, low spatial resolution of measurements, and lack of prior information about the response of structures at all possible damaged states. Additionally, the measured responses at various locations on a structure are statistically dependent due to their connectivity via the structural elements. Failure to accounting for such dependencies results in inaccurate predictions, usually by blurring the damage localization resolution. These challenges motivate further investigations on developing robust inference methods in this regard.

In our recent studies, we have proposed multiple inference techniques to address the challenges in structural health monitoring (SHM) related decision making problems under the above-mentioned constraints. The tradeoffs of using these inference methods are mainly about their computational cost, and the combination of these methods can handle a wide range of problems. To develop these inference techniques, we have utilized advanced learning algorithms, such as statistical graphical models and conditional classifiers, along with optimization methods in order to characterize the dependencies of structural response at different sensor locations. The results of experimental evaluations of the proposed methodologies in monitoring laboratory and full scale structures, and comparisons with peer methods show that considering the aforementioned dependencies can significantly improve damage localization accuracy. The efficacy of the proposed techniques in monitoring full scale structures also confirms that the outcomes of our studies can be regarded as a basis for practical monitoring of real civil structures and developing smart, resilient, and sustainable infrastructure systems.