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RESEARCH BRIEF

PROJECT TITLE: FINITE ELEMENT MODEL UPDATING AND DAMAGE DETECTION FOR BRIDGES USING VIBRATION MEASUREMENTS

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The continued functionality of a nation's infrastructure systems, e.g. bridges, is a necessary pre-requisite to her continued social and economic development. However, in about 15 years, 50 percent of our bridges will be over 50 years old, inducing an unprecedented commitment of both financial and human resources. Hence, a successful Structural Health Monitoring (SHM) strategy, providing reliable, economic and easy to conduct inspections, is essential to engineers and government authorities responsible for the up-keeping of such systems. Such a strategy will involve the collection of vibration response data of the bridge, through the analysis of which an instantaneous assessment of the bridge's current state of health can be made.

In vibration based SHM, statistical pattern recognition has attracted considerable attention over the past decade. Being solely data-based, this framework circumvents the uncertainties induced by modeling assumptions, and through its inherent statistical nature, accounts for the uncertainties induced by measurement noise, environmental/ambient effects etc. However, the performance of any particular method in this framework in successfully locating and quantifying damage depends on the particular damage sensitive feature (DSF) used. Due to the choice of the DSFs, which are often selected as abstract information with not very well-defined relationships to the structural properties, traditional damage detection algorithms developed within this framework can seldom locate and quantify damage, although they can accurately distinguish between a "damaged" and a "healthy" structural system. On the contrary, due to their intuitive relationship with the structural topology and characteristics, modal properties (natural frequencies and mode shapes) can be expected to solve the problems of damage location and quantification as well, if a modal parameter based DSF is so defined as to be tailored to that purpose.

In view of this, a "mixed" approach has been explored in this study, where the DSFs are defined using the modal properties, identified from the response of the bridge, while the damage detection, location and quantification procedures are developed according to the statistical pattern recognition paradigm. The proposed DSFs are tailored to be proportional to the change in stiffness between two states of the bridge, and hence referred to as Stiffness Proportional DSF (SPDSF). The methods of building a statistical model of the SPDSFs representing the "healthy" condition of the bridge, and of comparing this "healthy" model with the SPDSFs obtained from a hitherto unknown state of the bridge for damage assessment purposes, are developed according to the training and testing phases typical of the pattern recognition framework. During training, the uncertainties introduced into the SPDSFs by operational and environmental variability, i.e. by temperature, traffic, wind, etc., are explicitly taken into account through the construction of a range of Empirical Cumulative Distribution Functions (ECDFs) of the SPDSFs, defining boundaries of operational variability of these ECDFs.

The performance of the proposed method is discussed using numerical simulations of the bridge superstructure, including the situation of a limited number of sensors. The results show that this methodology is successful in detecting the occurrence of damage and, in the case of full sensor setup, also in accurately locating the element where damage has occurred and the amount of element stiffness reduction. In the case of a limited sensor setup, the proposed methodology is successful in identifying the occurrence of damage, and even though it loses accuracy in pinpointing the exact damage location, it still successfully identifies the region containing the damaged element. In conclusion, the results obtained using the proposed SPDSF are promising and allow for damage identification, localization and severity estimation.