Career development plan
– 1st year – XXXVIII Cycle (A.Y. 2022-2023)

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RESEARCH PROJECT (max 3 pages):

Probabilistic methods for Structural Health Monitoring of Bridge Networks

Introduction and state of the art:

Over the past two decades, structural health monitoring (SHM) has become a hastily growing area of research among structural engineers. Unlike traditional periodic and run-to-failure maintenance structures, SHM advocates the use of long-term non-destructive monitoring of structures to characterize the correlation between structural performance and different operational factors such as environmental or loading conditions to identify the presence of abnormalities in the structural functionality induced by structural damage.

The major task of SHM is identifying the damage, its location, and assessing its severity. Research in this field has been mainly focused on two distinct areas: a) development of sensing technologies and hardware, and b) providing computational and diagnostics tools to analyze and interpret the structural behavior data.

However, despite extensive research achievements have been reported in the first area, the second field has made less progress due to its inherent challenges. These stem from the difficulties in achieving a comprehensive and accurate framework for damage detection, localization, and characterization with a high level of reliability and providing robust measures of the uncertainty in the damage inference.

One of the most significant challenges in SHM procedure especially in pattern recognition is incomplete measured data, as well as unavailable labelling (representing the healthy condition and different damage states) to describe the measurements. Furthermore, uncertainty factors are inherent in measurements/observations in SHM, to some degree, and can stem from experimental sources (e.g. sensor accuracy limitations, precision or human error) or can be associated with simulation and machine learning (e.g. model discrepancy, interpolation error, and parametric variability).

Mitigating uncertainties (during data acquisition) and quantifying them (within the modeling procedure) represent key elements to provide damage identification results with confidence intervals, discriminate between scenarios, and consider decision-making factors such as safety, risk, and cost. Since probabilistic approaches can address the aforementioned issues and have the capability of making predictions of structural performance under uncertainty, which is a significant advantage in risk-based applications, we will employ them in our proposed framework.

The main scope of our research will be developing an SHM framework for the durability and vulnerability assessment of a network of bridges. The reason behind this selection is the undeniable importance of bridges in the transportation system, especially in the main corridors, and their tremendous impact on the daily life of the citizens and economic growth.

Bridge SHM is important from some points of view. Many bridge assets are built decades ago and most of them must now be rehabilitated. And generally, the main reasons for rehabilitation are:

(a) The insufficient knowledge of seismic design requirements at the time of bridge construction. (b) The increased live loads. (c) Underestimation of the effects of time on the concrete and other materials during the design and construction phase, and in some cases, (d) The poor quality of the construction.

Nonetheless, it is evident that the installation of dense monitoring systems in all the assets of the transport infrastructure at a national scale is economically unsustainable. Therefore, it would be desirable to count on efficient approaches capable of inferring the condition of the complete infrastructure network by exploiting monitoring records from a limited number of instrumented assets. In this light, we will develop a demand/capacity model for bridge structural assessment exploiting the information from a limited number of SHM systems installed on limited assets to achieve a more accurate estimate of the structural reliability of a complete bridge network. Since generally bridges located in a region are constructed following similar structural typologies, materials, and design guidelines, evaluating a limited number of assets and extending the results of the analysis to the whole of the network may lead to significant reductions in monitoring costs.

In addition, having such a network for probabilistic data inference that has the ability to update the health status of complete bridge networks plays a key role in the decision-making and prioritization rehabilitation process, and in retrofitting the bridge network immediately after accidental events (e.g. earthquake).

Research objectives:

1- Developing a solution for assessing the vulnerability of a bridge model in relation to a certain factor (such as seismic loading) and generalizing the results of the analysis and model updating of the target bridge (under monitoring) to other bridges in the network using artificial intelligence and machine learning.

2- Devise an efficient method to mitigate major challenges of probabilistic approaches such as high computational cost and quantifying uncertainties.

3- Combining and simultaneously applying the concepts of reliability, optimization, and structural health monitoring to develop a framework for decision-making for infrastructure management.

Methodology:

This research includes the areas of:

- Structural health monitoring (SHM): for controlling the current structural condition and making predictions of the structural performance,

- Machine learning: to facilitate information updating, identification of critical components and solve decision making problems, (Figure 1 illustrates a simple proposed Bayesian network as a machine learning technique for seismic bridge network SHM).

- Bridge engineering: for injection of engineering knowledge in the learning process through structural modelling,

- Probabilistic methods: for calculating reliability and risk,

- Optimization: to find a balance between conflict criteria of maintenance cost and probability of failure,

- Computer modeling: to simulate the structural behavior.

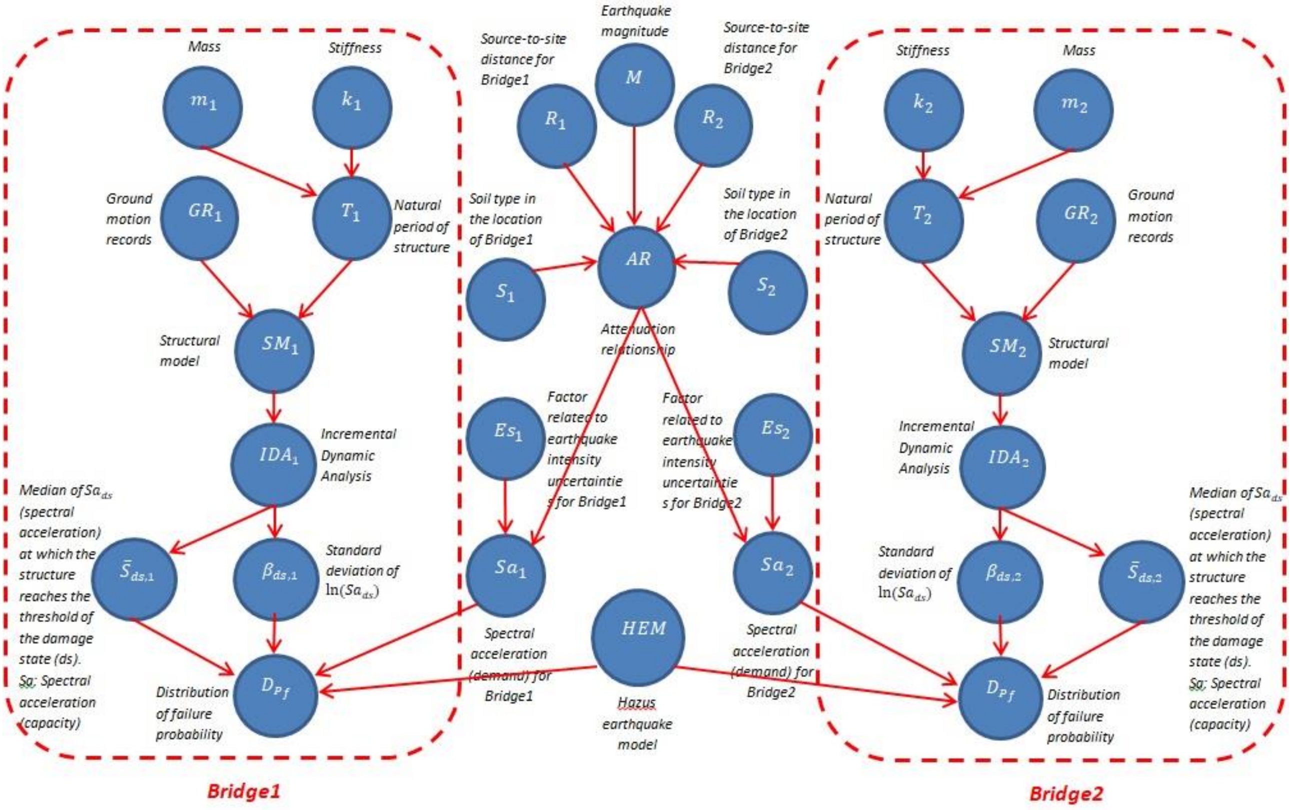

Figure 1- A proposed prototype of Bayesian network as a machine learning technique for achieving seismic failure probability distribution

Major components of the methodology are as follows

1) Defining a demand model, depends on the problem. It can be based on seismic loading, environmental conditions, or fatigue due to the dynamic effect of vehicles. And assessing probabilistic distribution to the input variables, and modeling errors in data. 2) Representing a capacity model of the structure and incorporating uncertainty characteristics and probabilistic variables and parameters. 3) Design an artificial intelligence (AI)-based framework for diagnostic and prognostic processes, model updating, and training data by machine learning. 4) Identifying common variables and factors between different assets in the bridge network and developing the complete network to compute the vulnerability of structures and updating the health status of assets based on real-time analysis and interpretation of continuous data from structural health monitoring. 5) Developing an efficient tool for infrastructure risk assessment and decision support for maintenance and rehabilitation strategies as well as minimizing computational demands.

Expected results

We expect that the outcome of this research will be a software package in a flexible computational framework based on machine learning to evaluate the durability and vulnerability of bridge networks with a limited number of instrumented bridges in the network and conduct multi class damage identification.

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