Optimisation of Multi-type Sensor Placement for SHM based on application demands

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Summary

The research presents a multi-objective optimisation problem for a multi-type sensor placement for Structural Health Monitoring (SHM) on a long span bridge. The problem is formulated for simultaneous placement of strain sensors and accelerometers (heterogeneous network) based on the application demands for SHM system. The primary demands for SHM are Modal Identification (MI) and Accurate Mode Shape Expansion (AMSE). The optimisation problem is solved through the use of Integer Genetic Algorithm (GA) to maximise a common metric to ensure adequate MI and AMSE. The performance of the joint optimisation problem solved by GA is compared with other established methods for homogenous sensor placement. The results indicate that the use of a multi-type sensor system improves the quality of SHM and the use of GA improves the overall quality of the sensor placement compared to other methods for optimisation of sensor placement.

Keywords: Long Span Bridge, Sensor Placement Optimisation, Mode Shape Expansion, Modal Identification, Modal Clarity Index, GA

1. Introduction

Structural Health Monitoring (SHM) has gained importance over the last two-three decades. SHM systems make use of accelerometers and strain sensors, displacement transducers etc. for performance monitoring and temperature, humidity sensors anemometers etc. to keep records of ambient conditions. The cost of procurement and deployment of these systems is veryhigh. Thus, there are severe limitations on the number of sensors available for deployment. Hence, it is of utmost importance to optimise the location of sensors in order to get the maximum information. The different types of sensors deployed on the structure give complementary information and hence in order to make optimal use of the resources, the problem should be treated in an integrated way. The present state-of-the-art deals with optimisation of only one type of sensor (homogenous network) which gives sub-optimal solution when more than one type of sensors are present in the network Hence, the present study aims at optimising the sensor placement for joint optimisation of strain sensors and accelerometers. The application demands chosen areModal Identification (MI) and Accurate Mode Shape Expansion (AMSE). Due to the large size of the optimisation problem when applied to a real structure, Genetic Algorithm (GA) has been employed for optimising the selected principles.

The study is carried on a validated numerical model of the Great Belt Bridge and the results obtained from the optimisation are compared with homogenous sensor placements using the Effective Independence Method (EFI) [1] and sensor placement using established methods for OSP.

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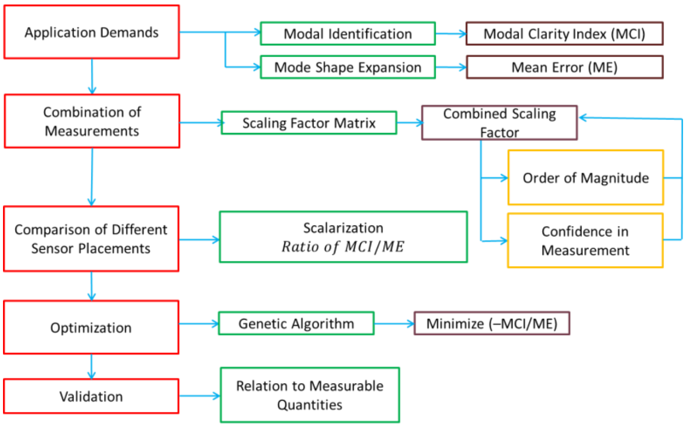

Fig.1: Overview of Sensor Placement Optimization Methodology

2. Methodology

The framework of methodology is outlined in Fig 1. MI and AMSE are chosen as the application demands. MI is essential for modal analysis and vibration based damage detection, while AMSE allows us to predict the response of the structure at locations which are not instrumented, based on the measurements at few locations.

Due to the combination of dissimilar quantities (modal strain and modal displacement from accelration data) the combined modal matrix is ill-conditioned. In order to perfrom accurate expansion the combined modal matrix needs to be conditioned using a scaling matrix. The scaling matrix is a diagonal matrix constructed as a combination of the order of magnitude of the measurement and the confidence in measurement. The scaled modal matrix may be used to compute the Modal Clarity Index (MCI) [2] and Mean Error (ME) using the System Equivaleent Expansion Reduction Process (SEREP) [3]. The GA is taken as the optimisation tool, and the ratio of MCI over MSE is taken as the optimization principle.

Table 1: Comparison of Sensor Placement Strategies using 200 sensors

Strategy	MCI Index	Mean Error	Ratio
Combined Sensor GA	0.73	6.56	1
Combined Sensors EFI	0.78	13.83	0.68
Accelerometers Only using EFI	1	22.65	0.27
Strain Sensors Only using EFI	0.07	1	0.19
Evenly Placed	0.26	11.27	0.53

3. Results and Conclusions

The results of optimisation are compared with optimised sensor placements for homogenous networks and optimisation using established methods of sensor placement as shown in Table 1. The combination of sensors gives a better fitness value than sensor placements based on homogenous placements. Also, the GA-based approach yields a fitness value which is significantly better than the other placement strategies.

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