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OPTIMIZING SENSOR PLACEMENT FOR VIBRATION AND DEFLECTION ANALYSIS IN BRIDGE STRUCTURES

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ABSTRACT

Accurate measurement of vibrations and deflections in bridge structures is essential for assessing their structural integrity and longevity. This study presents an optimization approach for the placement of sensors to measure vibrations and static deflections on a simplified 2D bridge model. The model, created using the Finite Element Method (FEM), includes key structural elements such as beams and columns. By analyzing both the natural frequencies and mode shapes of vibrations, as well as the deflections under static loads, we aim to derive precise values for stiffness and material density of the bridge components.

Our methodology involves: (1) developing a simplified 2D FEM model of the bridge; (2) simulating dynamic behavior to obtain natural frequencies and mode shapes; (3) conducting static load tests to measure deflections and derive stiffness and material density; (4) using an optimization algorithm to determine the most effective sensor positions based on the sensitivity of the measurements to changes in structural parameters.

This research addresses two primary objectives: the optimal placement of sensors for dynamic vibration analysis and the measurement of static deflections to determine structural parameters. Optimizing sensor locations enhances the identification accuracy of the desired parameters, ensuring that the collected data provides significant insights into the structural behavior of the bridge.

Integrating both dynamic and static analyses, our approach not only identifies the optimal sensor placement but also improves the overall accuracy of the structural assessment. Strategically placed sensors significantly enhance the precision of vibration measurements and static deflection data, leading to more reliable identification of material and structural properties. To achieve the optimization, we employ global optimization methods implemented in MATLAB [1], specifically the surrogate optimization technique and the pattern search method. These techniques are chosen for their efficiency in handling complex optimization problems with multiple variables and constraints.

Previous studies, such as those by Garbowski et al. (2023a), have shown the effectiveness of combining static and dynamic tests for structural diagnosis of bridges [2]. Cornaggia et al. (2023) have highlighted the importance of optimized structural modeling for parameter identification using

dynamic measurements [3]. Furthermore, Garbowski et al. (2023b) investigated Gaussian Processes optimization for parameter identification in historical bridges using dynamic modal measurements, providing a strong foundation for the optimization approach [4].

Motivation for this study arises from the growing need for efficient and optimized structural testing and monitoring of bridges, as highlighted by recent trends in engineering research [5–9]. The degradation of reinforced concrete bridges and other concrete structures due to intensive use, dynamic loads, and chemical processes necessitates accurate identification of changes in material properties over time [10–12].

This work contributes to the field of structural health monitoring by providing a comprehensive framework for sensor placement optimization. The findings have practical implications for the maintenance and safety evaluation of bridge structures, offering a cost-effective solution to accurately monitor and assess their condition. The proposed method can be extended to more complex structures and different types of infrastructures, paving the way for improved structural health monitoring practices.

In conclusion, the optimization of sensor placement, coupled with the analysis of natural frequencies, mode shapes, and static deflections, offers a robust approach to evaluating the structural parameters of bridge components. This research underscores the importance of strategic sensor deployment in enhancing the effectiveness of vibration measurement and static deflection analysis, ultimately contributing to the longevity and safety of bridge structures..

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