THESIS INFORMATION

INTRODUCTION

Official thesis title:	Develop advanced numerical methods for the optimization and structural health monitoring problem.
Major:	Civil & Industrial Construction
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CONTENT

Summary of findings of the thesis

This thesis introduces a novel single-step optimization approach for the simultaneous topology, size, and shape optimization of trusses subjected to multiple static and free vibration constraints. To achieve this, a topology pseudo-area variable, discretely assigned as either 10^{-3} or 1, is employed to represent the absence or presence of a truss member. This approach helps prevent the singularity of the global stiffness matrix during solving equilibrium equations, while maintaining the integrity of the finite element model structure, thus avoiding unnecessary and time-consuming finite element analyses. The cross-sectional area of the truss members serves as discrete or continuous size variables, while the spatial coordinates of the nodes are treated as continuous shape variables. The objective is to minimize structural weight under various constraints, including kinematic stability, stress, displacement, natural frequency, and Euler buckling load. To optimize both continuous and discrete variables, a hybrid Differential Evolution (DE) and Symbiotic Organisms Search (SOS) algorithm is refined and applied. The proposed method is tested through eight well-known examples involving the simultaneous topology, size, and shape optimization of 2D and 3D trusses with multiple static and free vibration constraints. The results demonstrate that the method yields competitive, high-quality solutions compared to other state-of-the-art algorithms. Additionally, the approach shows promise for application in large-scale truss optimization in practice.

In parallel, this thesis also proposes a novel model order reduction (MOR)-based two-stage damage detection method for trusses using time-series acceleration data from limited sensors. The first step introduces an acceleration-based strain energy indicator (ASEI) to identify the most likely damaged elements, significantly reducing the number of design variables in the inverse optimization problem of the second phase. Damage location and severity are then determined by minimizing an objective function enhanced with a dynamic penalty parameter, which accelerates convergence and improves the quality of solutions. Due to the incomplete measurement of acceleration signals, the second-order Neumann series expansion (SNSE) is used to condense the proportionally damped trusses and infer unmeasured time-history data. The inverse optimization problem is solved using an adaptive hybrid evolutionary firefly algorithm (AHEFA). Four numerical examples of 2D and 3D trusses, incorporating various damage scenarios and noise, confirm the reliability of the proposed methodology, demonstrating its capability to diagnose both the location and severity of damage with relatively short time histories and few sensors.

Finally, the study develops an optimally reduced-order isogeometric analysis (IGA) for investigating the transient behavior of functionally graded (FG) plates based on a four-variable quasi-3D theory. The dynamic characteristics of the plates are condensed using an iterated improved reduced system (IIRS) strategy, where the master degrees of freedom (DOF) associated with control points in the IGA framework are optimized via differential evolution (DE). This results in an optimal IIRS with naturally preserved consistent masses, leading to enhanced accuracy in high-order modal analysis. The four-variable quasi-3D theory further reduces the number of master DOF in the reduced-order models (ROMs) while accounting for transverse shear strain and normal stress, which higher-order shear deformation theories (HSDTs) often neglect. Additionally, the displacement field in the plate plane is approximated using non-uniform rational B-splines (NURBS) functions, and Galerkin's method is applied to derive the IGA-driven IIRS for transient analysis. The Newmark-β method is then used to solve the time-series behavior of the reduced system. Several examples are provided to validate the proposed methodology.

The applicability in practice

The optimization and diagnostic methods proposed in the dissertation have high practical applicability and can be immediately implemented in various critical fields. Specifically, these solutions improvethe performance and reliability of structures in industries such as construction, aerospace, automotive, and other industrial sectors. By applying derivative-free optimization algorithms and model order reduction (MOR) techniques, the design and optimization of complex structures—encompassing topology, size, and shape—become more efficient while minimizing costs and time in the stages of design, diagnosis, and maintenance. Additionally, in structural health monitoring, methods such as the acceleration-based strain energy index (ASEI) and MOR based on the second-order Neumann series expansion (SNSE) enable accurate damage detection using data from a limited number of sensors. This not only speeds up processing but also enhances solution quality, proving particularly valuable in ensuring safety and extending the lifespan of structures and equipment. These tools provide clear practical value by offering feasible solutions, optimizing resource utilization, and streamlining operational processes in real-world applications.

Further research directions

The HDS method will be further studied to extend for multi-objective optimization of topology, size, and shape of large trusses under seismic loads, and for optimization of reduced-order models (MOR) for frame, plate, and shell structures considering nonlinear behavior in the structural health monitoring (SHM). The limitations on accuracy under high noise levels and damage below 5% also need further investigation. The optimal placement, quantity of sensors, and excitation loads should be determined through optimization to maximize the effectiveness of damage detection. Additionally, experimental studies need to be conducted for comparison, aiming to tackle the shortcomings of the proposed numerical models.

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