Analysis, Control, and Design Optimization of Engineering Mechanics Systems

Esubalewe Lakie Yedeg

Akademisk avhandling

som med vederbörligt tillstånd av Rektor vid Umeå universitet för avläggande av filosofie doktorsexamen framläggs till offentligt föröv i hörsal MA121, byggnad MIT-huset, måndagen den 30 maj, kl. 10:15. Avhandlingen kommer att förövas på engelska.

Fakultetsavvanden: Professor Anton Evgrafov, Department of Mathematical Sciences, Norwegian University of Science and Technology, Norway.
Abstract

This thesis considers applications of gradient-based optimization algorithms to the design and control of some mechanics systems. The material distribution approach to topology optimization is applied to design two different acoustic devices, a reactive muffler and an acoustic horn, and optimization is used to control a ball pitching robot.

Reactive mufflers are widely used to attenuate the exhaust noise of internal combustion engines by reflecting the acoustic energy back to the source. A material distribution optimization method is developed to design the layout of sound-hard material inside the expansion chamber of a reactive muffler. The objective is to minimize the acoustic energy at the muffler outlet. The presence or absence of material is represented by design variables that are mapped to varying coefficients in the governing equation. An anisotropic design filter is used to control the minimum thickness of materials separately in different directions. Numerical results demonstrate that the approach can produce mufflers with high transmission loss for a broad range of frequencies.

For acoustic devices, it is possible to improve their performance, without adding extended volumes of materials, by an appropriate placement of thin structures with suitable material properties. We apply layout optimization of thin sound-hard material in the interior of an acoustic horn to improve its far-field directivity properties. Absence or presence of thin sound-hard material is modeled by a surface transmission impedance, and the optimization determines the distribution of materials along a “ground structure” in the form of a grid inside the horn. Horns provided with the optimized scatterers show a much improved angular coverage, compared to the initial configuration.

The surface impedance is handled by a new finite element method developed for Helmholtz equation in the situation where an interface is embedded in the computational domain. A Nitsche-type method, different from the standard one, weakly enforces the impedance conditions for transmission through the interface. As opposed to a standard finite-element discretization of the problem, our method seamlessly handles both vanishing and non-vanishing interface conditions. We show the stability of the method for a quite general class of surface impedance functions, provided that possible surface waves are sufficiently resolved by the mesh.

The thesis also presents a method for optimal control of a two-link ball pitching robot with the aim of throwing a ball as far as possible. The pitching robot is connected to a motor via a non-linear torsional spring at the shoulder joint. Constraints on the motor torque, power, and angular velocity of the motor shaft are included in the model. The control problem is solved by an interior point method to determine the optimal motor torque profile and release position. Numerical experiments show the effectiveness of the method and the effect of the constraints on the performance.

Keywords

Topology optimization, Helmholtz equation, acoustic impedance, anisotropic filter, thin structures, finite element method, Nitsche-type method, interface problem, Optimal control, adjoint method

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