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A virtual environment for engineering design optimization

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Abstract
The objective of this project is to combine virtual reality (VR) and engineering design to allow a designer to play an active role in the design sensitivity and optimization process. Virtual reality techniques provide a computer-generated environment for the designer to investigate multiple design changes while viewing and manipulating virtual objects by using human motion. Interactive design allows the designer to change design parameters and immediately determine the effect of the change by using sensitivity-based approximations. Combining virtual reality and interactive design techniques brings the designer directly in contact with the geometry of the design and the analysis results as design changes are investigated.

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Comments
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Abstract

The objective of this project is to combine virtual reality (VR) and engineering design to allow a designer to play an active role in the design sensitivity and optimization process. Virtual reality techniques provide a computer-generated environment for the designer to investigate multiple design changes while viewing and manipulating virtual objects by using natural human motion. Interactive design allows the designer to change design parameters and immediately determine the effect of the change by using sensitivity-based approximations. Combining virtual reality and interactive design techniques brings the designer directly in contact with the geometry of the design and the analysis results as design changes are investigated.

Introduction

Virtual reality is emerging as a powerful form of computer data visualization. Due to the increased complexity of modern design and manufacturing processes, visual representation of numerical data becomes more and more important as the designer strives to gain a better understanding of the problems. VR holds the potential for not only providing an efficient tool for data representation, but also allowing the designer to be an active partner in the design process. Thus the designer may use all of his/her prior knowledge about the problem as a tool in order to achieve a viable, optimal solution in a shorter lead time. This project focuses on developing a VR environment to facilitate structural design based on sensitivity methods and fast optimization techniques. The designer will be able to interactively explore design configurations in the neighborhood of the current design, and implement "what-if" studies in an attempt to improve the performance of the final design.

The software used in this project to develop the virtual environment is World Tool Kit™, a library of C functions, on Silicon Graphics™ workstations. The virtual environment peripherals consist of a FakeSpace BOOM3C™, a Virtual Research™ HMD (Head Mounted Display), a Cyberglove™ instrumented glove, and an Ascension Flock of Birds™ magnetic position tracker. The user is able to look through the BOOM3C™ or HMD, "reach out" into the virtual world with the Cyberglove™ to make design changes by manipulating the virtual objects or clicking the virtual menus, and see the effect of those changes on the virtual objects.

The following sections summarize some of the past and on-going studies associated with this research project.

Interactive Design Based on Sensitivity Analysis and Finite Element Results in a Virtual Environment [1]

This research incorporates finite element analysis (FEA) results into a virtual environment to facilitate interactive design. Sensitivity methods are used to make interactive changes and immediately view the results for finite element models in a virtual environment. Because finite element results cannot be calculated fast enough on traditional workstations to allow the designer to immediately view the effect that changing a design parameter has on the frequencies or stresses, the new displayed FEA results are computed using linear approximations based on sensitivity information derived from FEA software package. Here a commercial software package, MSC/NASTRAN™, is used to perform the FEA and sensitivity analysis of an automobile body frame. The modeshapes of the frame and the color contour plot of the VonMises stresses are displayed interactively as the stiffness of the suspension springs is changed.

Interactive Design Optimization in a Virtual Environment [2]

For the traditional numerical optimization method, the interaction a designer has with the optimization process is limited to the initial stage of problem definition. The interactive design optimization method presented in this project allows a designer to play an active role in the design optimization process. A key to this method is the use of designer-weight cost function [3]. Designer-weighted optimization gives the designer the ability to vary the contributions of several competing design objectives interactively by changing various weighting parameters in the objective function. In order to achieve interactive design, fast approximations to the objective function evaluations are also needed. First order Taylor series approximations are used in this project to approximate the eigenvalues and eigenvectors of a lumped spring-mass system. The designer is able to find the optimal solution of the system by changing the design variables through a virtual menu.

Virtual Panel Interaction

The desired interaction in a virtual world is more complex than just manipulating a virtual object. For example the design variables which are independent of the physical properties of the virtual object may need to be displayed. This type of interaction leads itself to a more menu-driven approach. Several menu systems have been explored including virtual control panels which occupy specific positions in the virtual environment, and "heads up" menus that stay fixed in the design space but can be hidden at times. The user can select menus or push buttons in the virtual environment by using the Cyberglove™. Another method of interacting with menus that is yet to be explored involves using a laser-beam-like pointer to point at the menus fixed in the space [4]. The on-going work is the development of a virtual menu data structure such that it maintains the database of 3-D hierarchical menu objects, and it can be reached by the user in a more natural and easy way.

Higher Order Approximation Method

In most real-world engineering problems, the relationship between the structural response and the design variables can be nonlinear, thus linear Taylor series approximations do not accurately represent the nonlinear relationship as the design changes become large. Whitesell [5] presented a method using Padé Approximants to overcome this difficulty and provide an approximation that is valid for large design changes. Vance [6] combined Padé Approximants and curve-fitting methods to estimate the natural frequencies and mode shapes of structural systems for large design changes. The on-going research is focused on the interactive optimization methods based on higher order approximations in order to gain a more accurate solution over a wide range of design changes.

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