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# Self-Consistent Electromechanical Analysis of Complex 3-D Microelectromechanical Structures Using Relaxation/Multipole-Accelerated Method

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In this paper we show that self-consistent electromechanical analysis of complicated three-dimensional structures can be performed by combining a fast multipole-accelerated scheme for electrostatic analysis with a standard finite-element method for mechanical system analysis. The approach is based on a relaxation scheme, and experimental results are presented to demonstrate that the relaxation converges rapidly for a variety of examples, and an example is given for which the relaxation diverges. Although not completely general, the relaxation approach does make it possible to perform self-consistent electromechanical analysis of very complicated three-dimensional structures in less than a few hours using an engineering workstation.

## 1. Introduction

Electrostatic microactuators, such as the suspended-polysilicon combdrive[1] and the electrostatic microvalve,[2] are typically controlled by applied voltages which create electrostatic forces to deform the structure. As the structure deforms, however, the electrostatic forces change, making the final structure's shape difficult to predict. For this reason, designers of microelectromechanical systems (MEMS) are making increasing use of simulation tools, especially finite-element-based mechanical analysis programs. Unfortu-