Position Paper: MEMS Applications in Sensors and Actuators – Optimal Design of MEMS

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Introduction: The most well-known industrial application of a MEMS sensor is an accelerometer in an automobile air bag. Although MEMS sensors are being increasingly used in other applications, I feel that a "killer app" is needed soon, if the vast promise of MEMS is to become a practical reality. A sampling of recent work in the area of optimal design of MEMS sensors and actuators is outlined below.

Topology Optimization: A vigorous research program, in the area of topology optimization of MEMS, is underway at the Technical University of Denmark, under the direction of Professor Ole Sigmund [1]. The goal of this project is to develop systematic tools for the design of MEMS using topology optimization and other structural optimization methods. The emphasis here is on a systematic approach to the design of sensors and actuators.
A "generic" problem in actuator design is described by this group as follows: given inputs such as forces, displacements, temperature change, electric or magnetic fields etc., design an actuator consisting of passive as well as active materials that will provide desired outputs of forces, displacements, vibrations etc. The design is carried out using principles of topology optimization that have been developed by Professors Bendsoe (also at the Technical University of Denmark) and Professor Kikuchi at the University of Michigan. A typical objective function to be maximized might be an output displacement or force, or the displacement of an output spring. The adjoint approach is employed for sensitivity analysis. The total Lagrangian nonlinear Finite Element Method is used. Large problems with up to 20,000 variables and 30 constraints have been attempted. Examples, such as synthesis of a two degree of freedom electrothermomechanical actuator are described in their WEB page [1]. Future work of this group will focus on dynamical systems, design of membranes, supports, etc.

Optomal Design of Variable-Gap Comb Drives: An electrostatic comb drive actuator, consisting of interdigitated capacitors, is one of the most important of MEMS devices. In a typical comb drive, the gap between the fixed and moving fingers is uniform, resulting in an electrostatic driving force that is independent of the position of the moving fingers except at the ends of the range of travel. It is possible, by changing this gap profile, to obtain different force profiles. It is of interest, in some applications, to have force profiles such as linear, quadratic, cubic etc. One example is a nonlinear driving force to overcome nonlinear restoring forces from springs, thus allowing for larger ranges of travel than possible otherwise.

In this work, variable gap comb drives, that produce desired force profiles, have been designed by posing inverse problems that are solved by using optimization procedures [2,3]. The objective function is chosen as the integral of the square of the difference between the actual and the desired force profiles. Design sensitivity coefficients are obtained by using the direct differentiation approach, and are then used to drive iterative optimization procedures. Designs of variable-gap comb drives with linear, quadratic and cubic driving force profiles are presented in ref. [2]. Based on these designs, a comb drive that produces a cubic polynomial driving force has been fabricated using the SCREAM I process at the Cornell Nanofabrication Facility. Test results show reasonable correlation between numerical simulations and experiments [3].

Research Priorities and Role of NSF: MEMS research, by its very nature, is interdisciplinary. By and large, NSF is organized as distinct divisions and programs within divisions. I feel that it is highly desirable that NSF should set up a procedure for soliciting interdisciplinary proposals in the MEMS area that are reviewed by interdisciplinary panels. Such panels should include, for example, electrical engineers, mechanical engineers, applied mechanicians, etc.

References:

1. The WEB cite http://www.topopt.dtu.dk
2. W. Ye, S. Mukherjee and N.C. Macdonald, Optimal design of an electrostatic comb drive in micro-electro-mechanical systems. Journal of Microelectromechanical Systems, Vol. 7, 1998, pp. 16-26.
3. W. Ye and S. Mukherjee, Design and fabrication of an electrostatic variable-gap comb drive in micro-electro-mechanical systems. Computer Modeling in Engineering and Sciences, Vol. 1, 2000, pp. 111-120.