MEMS Modeling

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1.1 Microelectromechanical Machines and Computation

What is MEMS?

- Using the fabrication techniques and materials of microelectronics as a basis, MEMS processes construct both mechanical and electrical components.
- MEMS is a fabrication approach that conveys the advantages of miniaturization, multiple components, and microelectronics to the design and construction of integrated electromechanical systems.
- All MEMS fabrication approaches share these three key characteristics.
Miniaturization brings many advantages to the performance of electromechanical devices and systems. Structures that are relatively small and light lead to devices that have relatively high resonant frequencies. These high resonant frequencies in turn mean higher operating frequencies and bandwidths for sensors and actuators. Thermal time constants – the rates at which structures absorb and release heat – are shorter for smaller, less massive structures.
But miniaturization is not the principle driving force for MEMS.

Because MEMS devices are by definition interacting with some aspect of the physical world such as

- Pressure,
- Inertia,
- Fluid flow,
- Light,
MEMS devise

Figure 2. The scale of MEMS technology: a MEMS on-chip laser and optical system (the small rectangle overlaid on the ruler) is shown here on the same scale as a single dandelion seed—something so small and light that it literally floats in the air.

Figure 3. The laser from Figure 2, in detail. This MEMS laser, with optics suitable for transmitting light off-chip, gives an idea of what is technologically possible today. It was fabricated by Lih-Yuan Lin and Shi-Sheng Lee in Ming C. Wu’s research group at UCLA.
Multiplicity

Multiplicity, or the batch fabrication inherent in photolithographic-based MEMS processing, is as important as miniaturization.

It provides two important advantages to electromechanical devices and systems.

Multiplicity makes it possible to fabricate ten thousand or a million MEMS components as easily and quickly as one.
The second, equally important advantage of multiplicity is the additional flexibility in the design of massively parallel, interconnected electromechanical systems.

The multiplicity characteristic of MEMS has already been exploited in the development and recent demonstration of a digital micromirror display.

In an array about the size of two standard postage stamps, over a million mirrors-each the size of a red blood cell-collectively generate a complete, high-resolution video image.
Finally, neither the miniaturization nor the multiplicity characteristics of MEMS could be fully exploited without microelectronics.

The microelectronics integrated into MEMS devices provides the latter with intelligence and allows closed-loop feedback systems, localized signal actuator arrays.

The considerable investment that has been put into microelectronics materials and processing, and the expertise built up in this field, is helping the development of MEMS devices.
Microelectromechanical Machines and Computation

- MEMS is an exciting applications area
- MEMS devices use fabrication technology similar to traditional semiconductor chips but operate as mechanical as well as electrical devices
- The design of MEMS devices is still very much an art based on practical experimentation
MEMS design inherits all the difficulties of modeling electrical semiconductors; additionally, it requires thermal and structural modeling to simulate the mechanical properties of MEMS devices.

Surface tension from humidity can also become a major physical force at the microscopic level.
1.2 Efficient MEMS Simulation: Three main computational challenges

- The action of MEMS devices such as silicon micro-accelerometer involves several physical effects:
  - mechanical motion,
  - air damping,
  - electrostatic action,
  - and capacitive position detection.
Detailed knowledge of all of these effects is a prerequisite for effective and efficient design.

The first step in reducing design time and allowing for aggressive design strategies is to develop simulation tools that will let designers try “what if” experiments in hours instead of months.
Three computational challenges

- First, faster algorithms are being developed for computing surface forces due to fields or fluids exterior to geometrically complex, flexible three-dimensional structures.
- Second, since the performance of most micromachined structures is due to a complicated interaction between structural stress, electrostatic or magnetic forces, and fluid tractions or pressures, approaches for coupling efficient domain-specific solvers are under investigation.
Finally, when it is embedded in a completed system, designers need accurate dynamical models that permit rapid simulation of system performance under a wide variety of inputs and scenarios, such as being inserted into a feedback loop.

And since direct simulation of 3D structures involves thousands of degrees of freedom, all coupled together, full nonlinear direct dynamic simulation can be computationally infeasible in a typical workstation environment.

Furthermore, designers tend to think in terms of models with only a few degrees of freedom that are well correlated to modifiable parameters like dimensions or material properties.