Robust Control of MEMS with Electrostatic Actuation and Large Deflections

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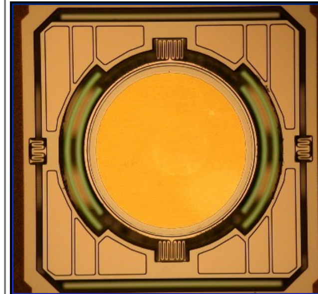
Goals and Potential Impact if Successful

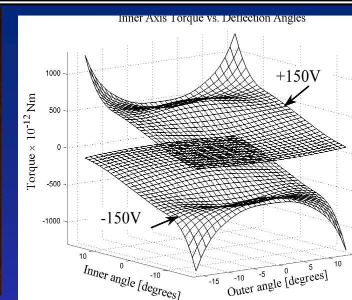
Develop robust control strategies for precision control of electrostatically actuated MEMS actuators.

- Applications: micromirrors for optical switching, MEMS accelerometers, MEMS gyroscopes, micromirrors for laser targeting and communication.

Practical considerations:

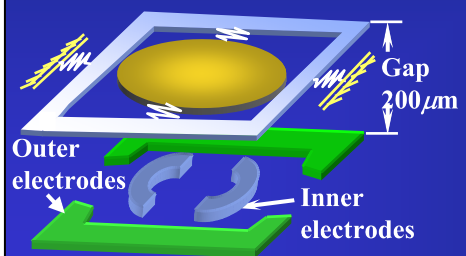
1. Optical switching applications require **high precision** (11bit dynamic range – 5mdeg precision with 15 degrees range)
2. Implementation in **integrated** sense-control circuits to reduce noise, time lags and facilitate scalability.
3. **Robustness** to Lithographic and microfabrication variations in device parameters (could be as much as ±50%).
4. Stability and performance over all operational conditions.
5. Fault detection and **drift correction**: humidity, temperature.





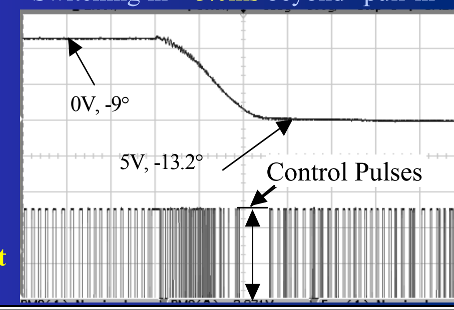
Torque is a nonlinear function of deflection angles and applied voltage.

IntelliSuite **™** is used for Electrostatics and MEMS modeling.



Two-axis micromirrors manufactured at Corning-IntelliSense, Inc.

Switching in ~ 3.0ms beyond "pull-in"



Approach and/or Accomplishments

Discrete-time implementation of a **modified** (adaptive) **sliding mode control** algorithm was successfully demonstrated for **two-axis micromirror** devices for optical switching applications.

1. ***IntelliSuite*™** used for calculating MEMS dynamical properties. Experimental validation of dynamical models. The dynamical model include out-of-plane translation modes as well.
2. **Sliding mode control** (SMC) provides excellent robustness and a stable operating range of ±15 degrees. *Modified* SMC involves adaptive sliding manifold for increased precision.
3. Integrated ASIC sense/control implementation demonstrated. **Capacitive sensing** for angular deflections.
4. Outer loop for temperature/humidity drift compensation.

Other theoretical research: *Nonlinear control of Hammerstein systems*. Hammerstein systems are linear systems with static state and/or control dependent input nonlinearity (e.g. electrostatics).

Bottlenecks and Open Research Questions

- Algorithms that provide provable stability (Lyapunov based) and robust operation over the nonlinear range. Electrostatic actuation is inherently unstable for large deflections. The linearized dynamics are unstable beyond the pull-in point.
- Feedback linearization, back-stepping and other nonlinearity compensation methods have to address the inherent nonlinearity and the effect of parametric variations.
- Control is not affine. Electrostatic nonlinearity is quadratic. Affine control methods may not applied for *single-sided* actuation (only positive control inputs).
- Implementation: reliable PWM/PM methods for discrete-time implementation in integrated circuits.

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