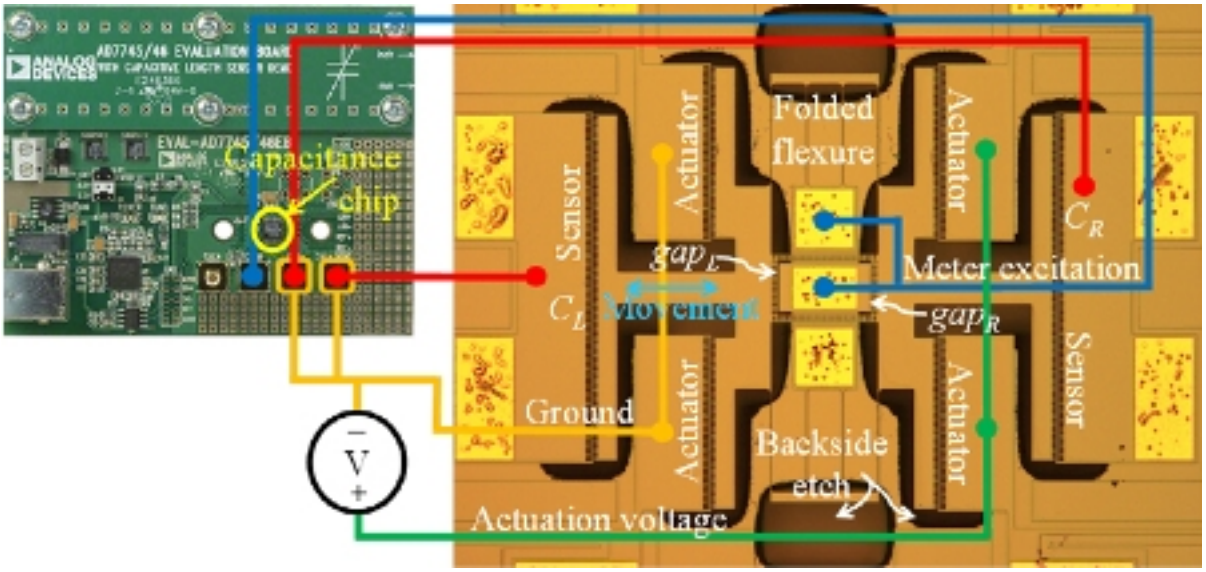
# New 'self-calibrating MEMS' bringing accuracy to nanotech




Researchers have demonstrated tiny machines that could make possible super-accurate sensors and motors, with far-reaching applications from computer storage to altimeters, detecting petroleum deposits to measuring DNA-binding forces.

The machines are called self-calibratable micro-electromechanical systems, or MEMS. Although MEMS are in commercial use, the new device is the first of its kind capable of self-calibration, a step critical for applications requiring high performance and accuracy, said Jason Vaughn Clark [1], an assistant professor of electrical and computer engineering and mechanical engineering at Purdue University.

"Self-calibration is needed because each MEMS device is slightly different due to variations that occur in manufacturing," he said. "Small variations in microstructure geometry, stiffness, and mass can significantly affect performance. Because of this variability, no two MEMS behave identically. Since conventional methods to measure MEMS properties are usually impractical, expensive, have unknown accuracy and large uncertainty, enabling MEMS to calibrate themselves is a game-changing innovation."

Clark previously developed the self-calibration theory. He and doctoral student Fengyuan Li have now created the device and conducted experiments to validate the theory. Findings are detailed in a paper to appear later this year in the IEEE Journal of Microelectromechanical Systems, or JMEMS.

The peer-reviewed work received a grade of A for "innovation" and an A for "importance to the field," which testifies to the significance of the research, Clark said.

"I think it's important to note that in 1990 MEMS pioneer Richard Muller said

research on the mechanical properties of the materials in these devices is needed to provide the engineering base that will make it possible to exploit fully this technology," he said. "And during a 2007 visit to Purdue, physics Nobel laureate John Hall said that without accurate and precise measurements, no reliable form of science or engineering is possible."

The self-calibrating technology makes it possible to accurately measure displacement, or how far a measuring device moves, on a scale of micrometers to less than a nanometer - a range that spans a fraction of the diameter of a human hair to a fraction of the width of an atom.

"The difficulty in accurately measuring small displacements represents a bottleneck in MEMS and nanotech advancements," Clark said. "Accurate metrology is a problem that has eluded researchers since the beginning of MEMS and nanotech in the late 1980s. Displacement is fundamental to science and engineering. We know that quantities like velocity, acceleration, force, stiffness, frequency, and mass can be related to displacement. Now, using a $15 chip that can fit on your fingertip, we showed that our technology is able to measure MEMS displacements better than a $500,000 electron microscope."

Introducing accurate measurement methods made the difference between alchemy and chemistry about 230 years ago, and self-calibrating MEMS might bring a similar transformation in the world if nanotechnology, he said.

"The ability to perform accurate measurements is of paramount importance to technological advancement," he said. "In the late 1700s, Antoine Lavoisier transformed alchemy to chemistry by introducing quantitative measurements. Today, some compare the state of micro and nanotechnology to alchemy, where nanotechnologists can precisely sense small signals, but they have not had a practical way to accurately measure most mechanical quantities. That is, no two nanotechnology labs have been able to show that they can measure the same phenomenon and obtain the same numerical result."

The heart of the self-calibrating MEMS are two gaps of differing size, electrostatic sensors and tiny actuators called comb drives, so named because they contain meshing comb-like fingers. These meshing fingers are drawn toward each other when a voltage is applied and return to their original position when the voltage is turned off. The comb drives measure the change in an electrical property called capacitance while gauging the distances of the two gaps built into the device. The fine measurements reveal the difference between the device's designed layout and the actual dimensions.

"Once you learn the difference between layout and fabrication, you have calibrated the device," Clark said. "Many MEMS designs with comb drives can be easily modified to implement our technology. Our research results suggest the days of inaccurate micro and nano-mechanical measurements are numbered."

MEMS accelerometers and gyroscopes currently are being used commercially in products such as the Nintendo Wii video game, iPhone, automobiles, the Segway

human transporter and walking robots. However, those MEMS don't require ultrahigh accuracy like those used in tactical- and navigation-grade inertial sensors, which must undergo a complex calibration procedure in the factory. The chips are tested using machines that translate, rotate, shock, and heat the devices.

"The new self-calibratable MEMS could eliminate or reduce the need for rigorous factory calibration, cutting manufacturing costs," Clark said. "Something like 30 percent of manufacturing costs are related to calibration."

The self-calibratable MEMS could lead to high-performance data storage technologies and advanced lithography to create next generation computer circuits and nanodevices.

Researchers will use the new self-calibration approach to improve the accuracy of atomic force microscopes, or AFMs, which are tools essential for nanotechnologists. Purdue operates about 30 AFMs, and Clark's research group will use the calibrated MEMS to calibrate AFM displacement, stiffness, and force.

The group also will use a calibrated MEMS to measure the difference in gravity between different heights above the ground. The ability to measure gravity with such sensitivity could be used as a new tool for detecting underground petroleum deposits.

"Conventional gravity meters can cost over $200,000," Clark said. "They consist of a large vacuum tube and a mirrored mass. Gravitational acceleration is determined by measuring the drop time of the mass in free fall. Since oil or mineral deposits have a different density than surrounding material, the local gravity is slightly different."

The bulky and expensive gravity meters could be replaced with a small and inexpensive MEMS chip. Another potential application is as an altimeter for aircraft. Conventional altimeters measure height by using air pressure, which fluctuates.

"These altimeters aren't really accurate," Clark said. "Having a sensor that could accurately determine height would be an asset while flying at night, through fog, or bad weather.

The self-calibratable technology also could allow MEMS to recalibrate themselves after being exposed to harsh temperature changes or remaining dormant for long periods.

Yet another potential application is the study of exotic phenomena such as forces between molecules and within tiny structures on the scale of nanometers.

"A more accurate MEMS device could make it possible to measure physical phenomena that have been beyond the resolution of conventional technology," Clark said. "To fully understand and exploit the attributes of the nanoscale, you really have to be able to accurately measure subtle phenomena. Without accurate measurement tools, it becomes difficult to discover or resolve these phenomena, to

develop accurate physical models, and to subsequently use the models to explore possibilities leading to useful innovations."

The work is based at the Birck Nanotechnology Center in Purdue's Discovery Park. The research is funded by the National Science Foundation.



**Links:**
[1] https://engineering.purdue.edu/ECE/People/profile?resource_id=21964