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Using capacitive sensing to create robust, low-cost force-torque sensors for real-world robotics

Stanford scientists have developed an innovative capacitive 6-axis force-torque sensor priced under $10—significantly more affordable than conventional sensors costing $1000+. The design, utilizing printed circuit boards with silicone pillars, withstands overloading that typically damages metal-based sensors. This technology enables practical force sensing in multi-fingered robot hands, contact-based drone operations, and surgical applications where existing sensors are either too costly for widespread implementation or insufficiently durable for challenging environments.

Conventional force-torque sensors rely on measuring microscopic deformations in metal bodies through strain gauges, making them susceptible to permanent damage from unexpected impacts. These sensors also typically cost over $1000 each, severely limiting their practical application in multi-sensor systems like robotic hands or environments with unpredictable forces. The robotics industry has long needed a solution that combines durability with affordability, particularly as robots increasingly operate outside controlled environments. Applications requiring force feedback—from drone-based infrastructure inspection to agricultural harvesting and surgical procedures—remain underdeveloped due to these limitations in sensing technology.

Stanford's capacitive sensing approach fundamentally addresses the limitations of current force-torque sensors. The design incorporates two printed circuit boards with silicone pillars as the dielectric material, enabling the sensor to withstand significant impacts while maintaining consistent performance—unlike strain gauge sensors that fail when subjected to unexpected forces. The system simultaneously detects all six axes of force and torque through a specialized electrode pattern and microcontroller-based signal processing that enables selective sensitivity adjustment. Testing has confirmed the technology delivers comparable performance to commercial alternatives at approximately 1% of their cost. This innovation represents a significant advancement that makes comprehensive force sensing practical for robotics applications where traditional sensors have proven either too fragile or prohibitively expensive.

Stage of Development:
Prototype
Continued research - Current development focuses on refining the fabrication process to ensure consistent sensor characteristics and exploring manufacturing techniques for cost-effective production at scale.

Applications

- Integration into multi-fingered robotic hands for dexterous manipulation and precise grasping
- Enabling contact-based tasks for drones such as infrastructure inspection and sensor deployment
- Enhancing surgical robotics with affordable force feedback for improved procedural safety
- Agricultural automation requiring tactile sensing for delicate crop handling
- Tool manipulation in unstructured environments where unpredictable forces occur
- Robot manipulation data collection devices (wearable or hand-held) for creating a multimodal large robot dataset that is 'touch-aware'
- Haptic feedback systems for teleoperated robots in hazardous environments

Advantages

- Exceptional durability against overloading in the compressive direction compared to traditional metal-based sensors
- Cost-effective design at under $10 per unit versus $1000+ for comparable commercial sensors
- Compact form factor allowing integration into space-constrained robotic systems
- Comprehensive six-axis measurement in a simple two-layer design

- Selective sensitivity adjustment for optimizing performance across different force ranges
- Scalable manufacturing approach using standard electronic components and processes
- Practical implementation in unpredictable real-world environments where conventional sensors fail

Publications

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