Tri-modal Flexible Electronic Skin to Augment Robotic Grasping

Novelty Claims

This paper reports a combination of three sensing modes (piezoelectric, strain, capacitive) for measuring relative movement, absolute movement, and proximity, respectively, on robotic structures. Two modes, piezoelectric and capacitive, are silver traces on a thin flexible layer of polyvinylidene fluoride (PVDF). Strain is measured using silver traces on a thin elastomer, polydimethylsiloxane (PDMS). A compliant layer of open-cell foam has been placed underneath the sensing layers to further increase the sensitivity of the system.

Background

Robotic grasping is successful when a robot can sense and grasp an object without letting it slip. Beyond industrial robotic tasks, there are two main robotic grasping methods. The first is planning-based grasping where the object geometry is known beforehand and stable grasps are calculated using algorithms. The second uses tactile feedback. Currently, there are capacitive sensors placed beneath stiff pads on the front of robotic fingers [1]. With post-execution grasp adjustment procedures to estimate grasp stability, a support vector machine classifier can distinguish stable and unstable grasps [2]. The accuracy across the classes of tested objects is 81% [2]. We are proposing to improve the classifier's accuracy by wrapping flexible sensors around the robotic finger to gain information from the edges and sides of the finger.

Multimodal tactile sensors are generally inflexible and are either silicon-based or combined on printed circuit boards. Overcoming this challenge requires combining various flexible tactile sensors. PVDF is a piezoelectric polymer used for relative movement tactile sensing [3]. For absolute force measurements, strain gauges built on elastomer substrates are used [4]. Lastly, capacitive sensing has been demonstrated by using electrode arrays to measure changes in the fringing electric field [5]. This work presents the material processing and device performance for a system of three sensor modes placed on top of a compliant layer to increase overall sensitivity.

Methods

Photolithographically-patterned 40 nm-thick silver electrodes thermally evaporated onto 52 µm-thick PVDF are used for relative displacement measurements. Charge from PVDF capacitors provides an estimation of relative movement. Voltage across the electrodes is measured using an instrumentation amplifier and low-pass filtered. Traces for capacitive sensing enable the measurements of raw digital counts using CapSense (Cypress Semiconductor, USA). Silver serpentine traces thermally evaporated onto 50 µm-thick spin-coated PDMS are used for measuring changes in resistance and thus detect applied force. Designs are shown in Figure 1. The gauge factor of the strain gauges is found by bending the devices on acrylic arches of various radii to induce bending tensile strain.

Various thicknesses of open- and closed-cell foam were tested to measure the sensitivity of the sensing modes, as shown in Table 1. Sensing layers were adhered to the compliant layer, which was adhered to a platform. An Admet force testing system was used to apply controlled amounts of force between 0.5 and 10 N to the sensing layers.

Results

Three modes were fabricated and characterized. Photographs are shown in Figure 2. An example signal output from the PVDF-based sensor is shown in Figure 1c. The gauge factor of the strain gauges was found to be 2.83 as shown in Figure 1d. Capacitance readings demonstrated a SNR of 962 fore proximity measurements, as shown in Figure 1e.

The sensor stack, specifically the relative movement sensing layer, showed increased sensitivity due to the presence of a thin hard open-cell polyurethane foam as the compliant layer, as shown in Figure 3. Obtaining relative (slip) and absolute (normal force) information from the edges of robotic hands will enable feedback for robotic grasping. The proposed system is currently being tested for grasping various objects using a Barrett Hand.

Word count: 587

References: [1] barrett.com [2] H. Dang and P. K. Allen, *Auton. Robots*, vol. 36, no. 4, pp. 309–330, Aug. 2013. [3] C. Li et al., *J. MEMs*, 17, 334-341, 2008. [5] M. Kim et al., *IEEE MEMs*, 1162–1165, 2017. [6] H.K. Lee et al., *IEEE Sensors*, vol. 9, no. 12, Dec. 2009.

Tri-modal Flexible Electronic Skin to Augment Robotic Grasping

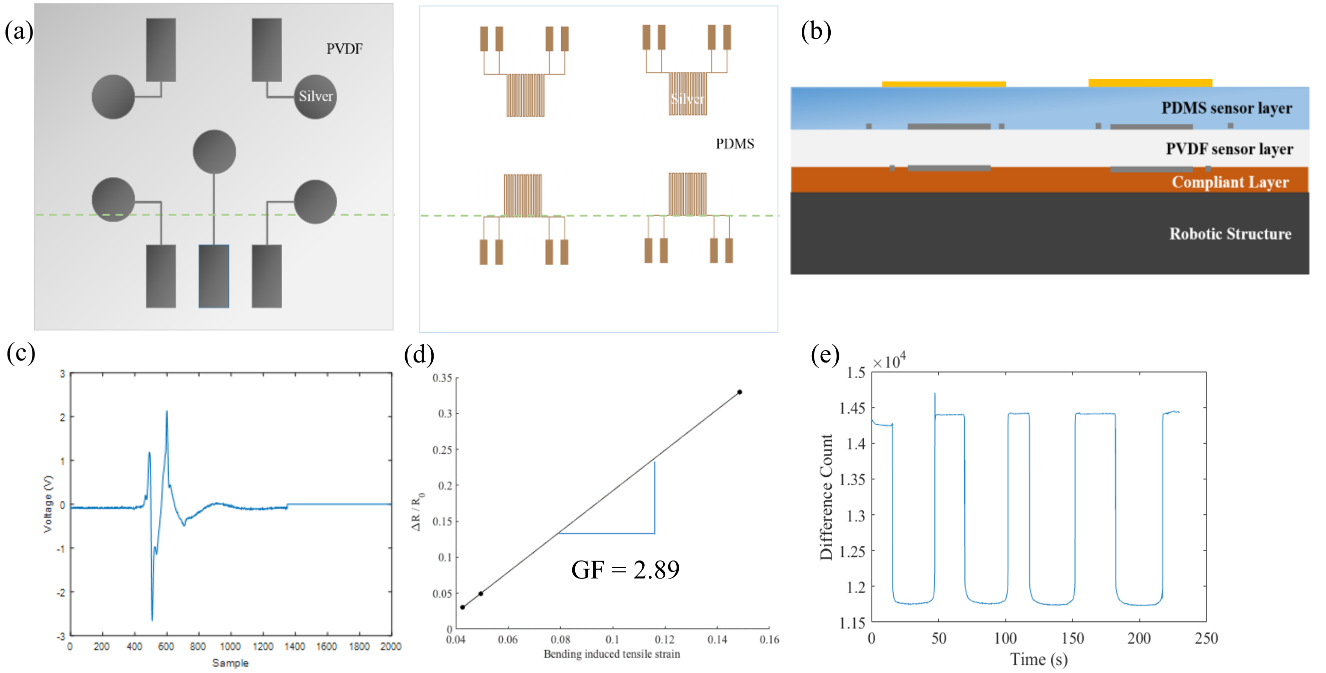

Figure 1: (a) Top-view of electrodes on PVDF and strain gauges on PDMS designs (b) Cross-sectional view of layer stack (c) PVDF voltage output corresponding to negative and positive physical displacement (d) Gauge factor of strain gauge (e) Change in capacitance measured by CapSense for proximity measurements

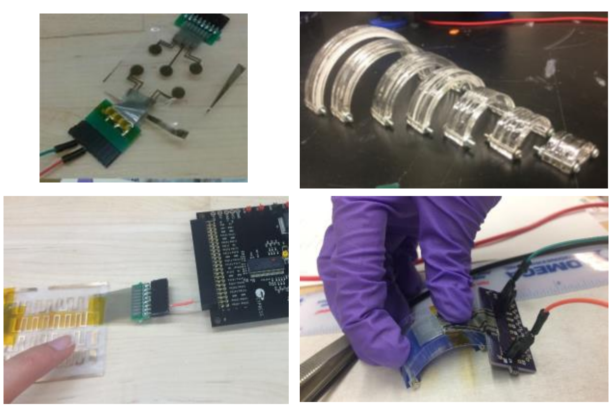

Figure 2: From top-left clockwise: 1) Metal electrodes on PVDF 2) Arcs used to apply bending induced strain 3) Bent strain gauge 4) Proximity measurement setup

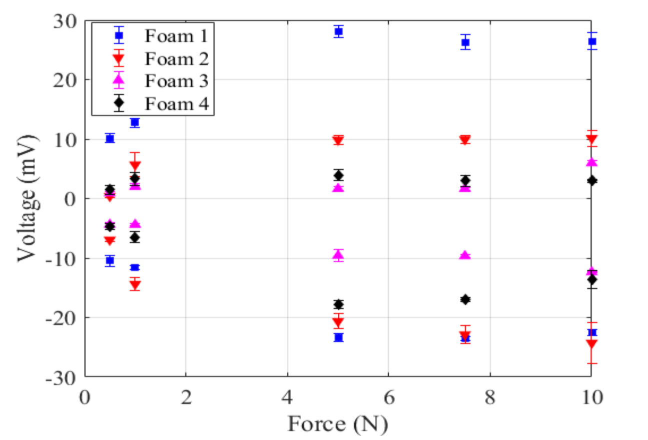

Figure 3: Voltage output of the PVDF sensor for various foams acting as the compliant layer. Foams listed correspond to those in Table 1.

Table 1

Foam	Compliant Layer	Cell Type	Thickness (mm)	Pressure to Compress 25% (psi)
1	Polyurethane Foam	Open	0.734	45
2	Silicone Foam	Closed	0.810	10
3	Neoprene/EPDM/SBR	Closed	1.59	7
4	Silicone Foam	Open	1.59	3