

Tactile sensing for real-time pipe inspection

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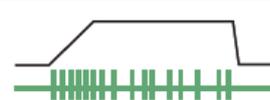
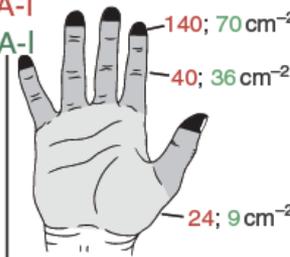
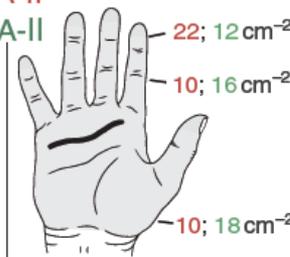


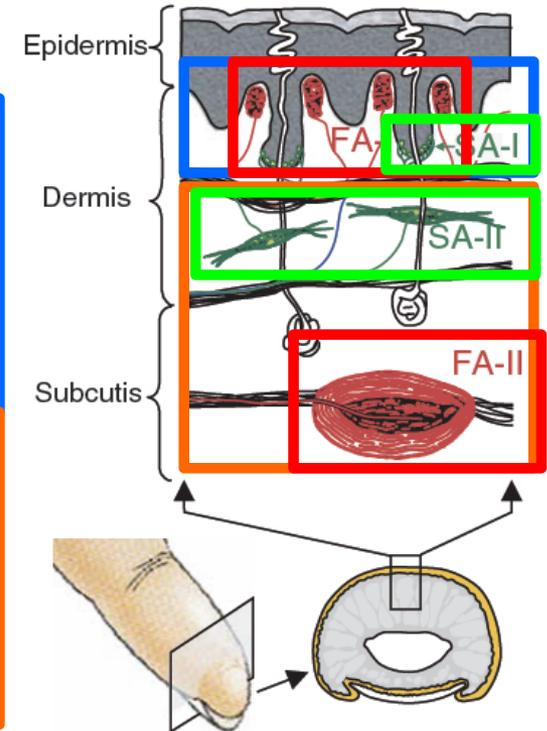
Human touch as inspiration

Biological mechanoreceptors

Superficial

Deep

Adaptation		Receptive fields	Innervation density
Fast, no static response	Slow, static response present		
 <p>Changes in fingertip forces, fine form discrimination, moving stimuli, slips, friction, etc.</p> <p>(43%) Meissner</p> <p>FA-I</p>	 <p>Irregular</p> <p>Finger tip forces, fine form discrimination, etc.</p> <p>(25%) Merkel</p> <p>SA-I</p>	<p>Small, sharp borders</p> 	<p>Increase distally</p> <p>FA-I: 140; 70 cm⁻²</p> <p>SA-I: 40; 36 cm⁻²</p> <p>FA-II: 24; 9 cm⁻²</p> 
 <p>Mechanical transients and vibration (~40–400 Hz)</p> <p>(13%) Pacini and Pacini-like</p> <p>FA-II</p>	 <p>Regular</p> <p>Directional strain in deep dermal and subdermal tissues</p> <p>(19%) Ruffini</p> <p>SA-II</p>	<p>Large, obscure borders</p> 	<p>~Uniform</p> <p>FA-II: 22; 12 cm⁻²</p> <p>SA-II: 10; 16 cm⁻²</p> <p>SA-I: 10; 18 cm⁻²</p> 



Excerpted from Johansson and Flanagan, "Tactile Sensory Control of Object Manipulation in Humans" (2007)

Human touch as inspiration



Commercially available tactile sensors



Microswitch



Force sensing resistor



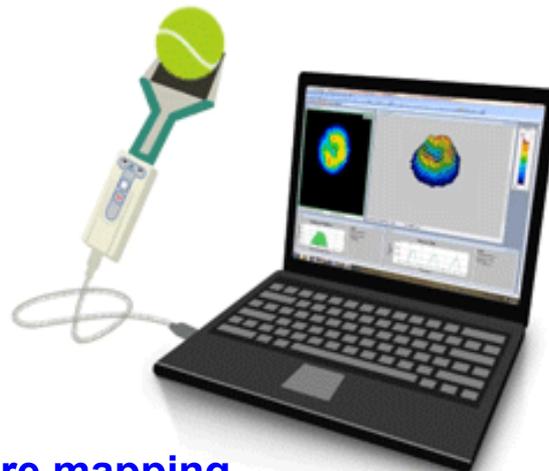
Force/torque sensors



Multimodal, elastomeric sensor *



Pressure mapping



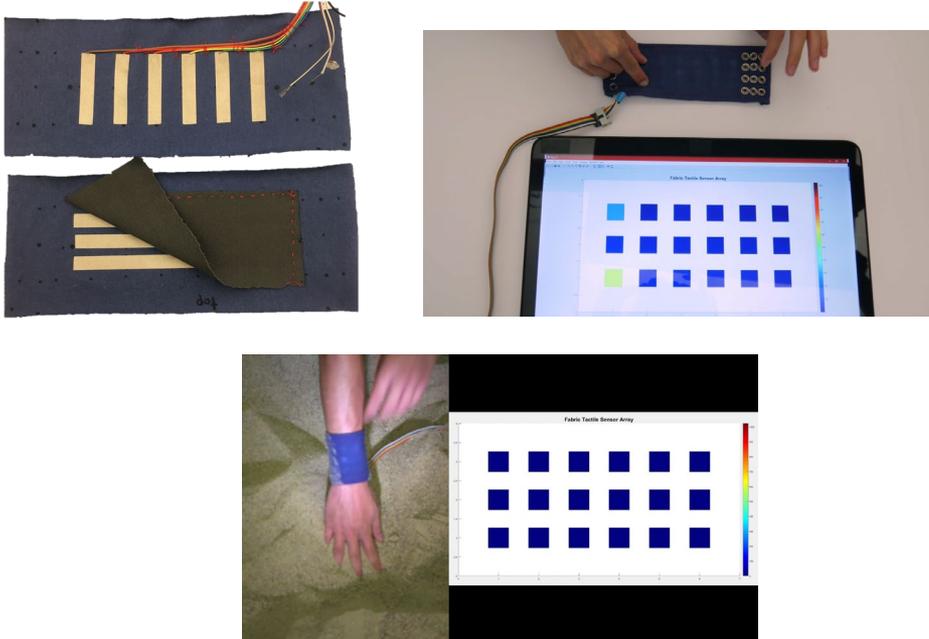
Vision-based elastomeric sensor

* **DISCLOSURE:** While I was not involved in the development of the company that produces the BioTac, I was a co-inventor of related intellectual property and have received royalty payments. I also serve on the Board of Advisors.

Images (clockwise): bananarobotics; interlinkelectronics; ATI Industrial Automation; SynTouch; GelSight; TekScan; PPS

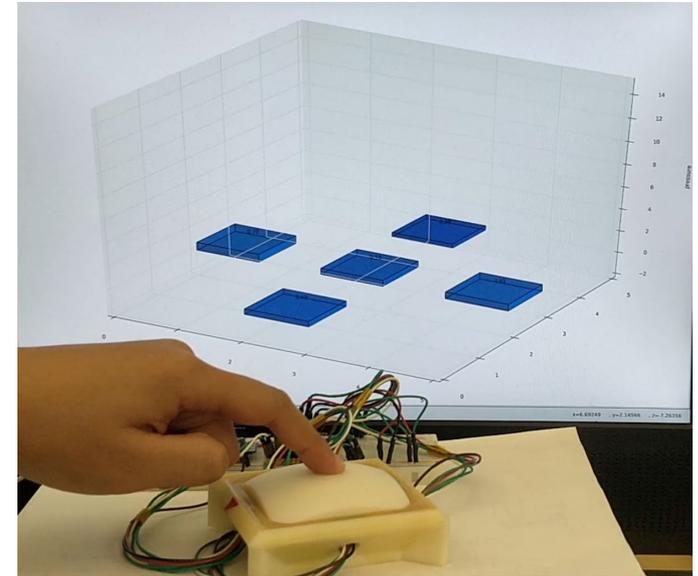
Low cost, scalable sensors

Piezoresistive fabric sensors



Inspired by Bhattacharjee, Rehg, and Kemp's fabric-based array

Barometric pressure sensors



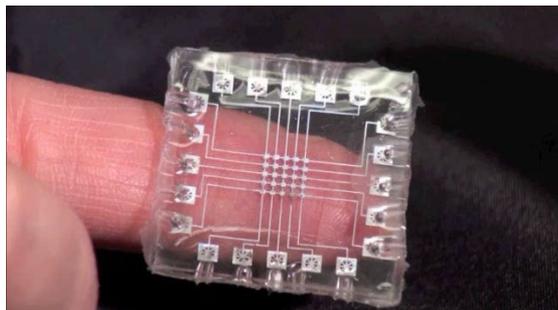
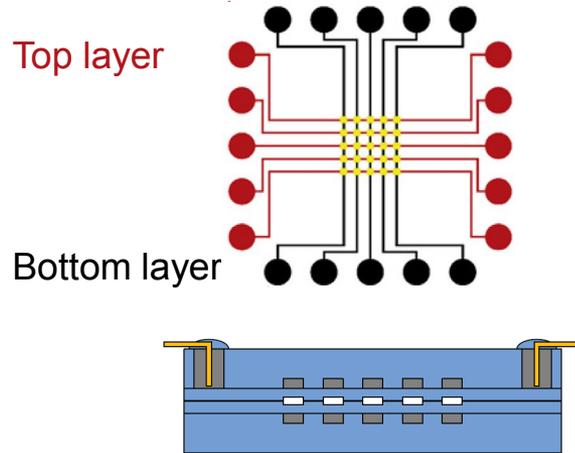
Inspired by Tenzer, Jentoft, and Howe's TakkTile



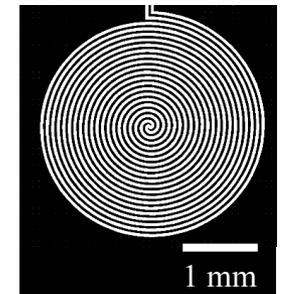
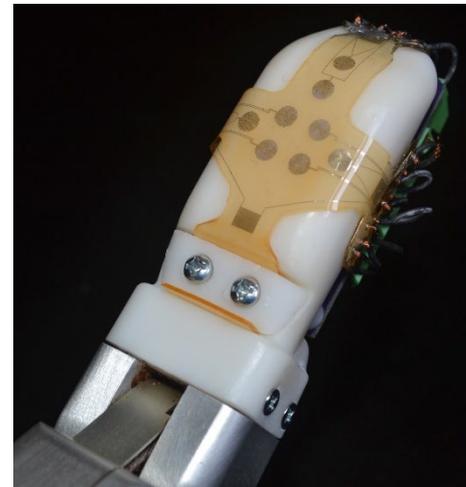
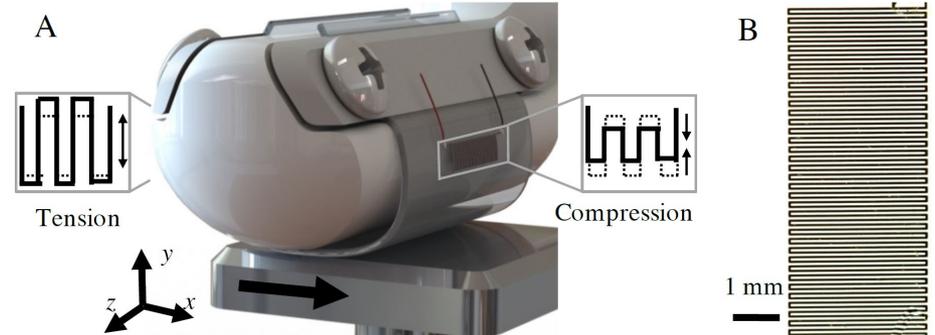
Day, N., Peñaloza, J., Santos, V.J., and Killpack, M.D. "Scalable fabric tactile sensor arrays for soft bodies," *J Micromech Microeng*, Special Issue on "Soft robotics and smart system technologies," 2018.

Deformable, multimodal tactile sensor skins

Capacitive-based
normal force sensors



Resistive-based
normal force, shear force, vibration sensors



ASU W

In collaboration with
Dr. Jonathan Posner,
Univ. of Washington



UCLA W

Human haptic perception

Visual feedback is often limited or absent



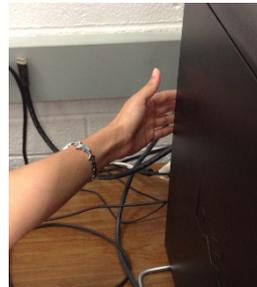
No line of sight



In the dark

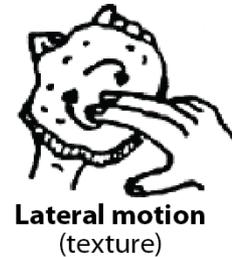


Inside containers

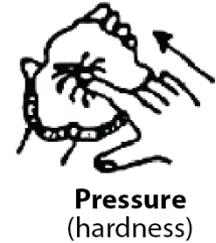


Around obstacles

Abstracting to substance and structure-related properties



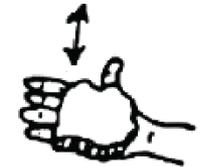
Lateral motion
(texture)



Pressure
(hardness)



Static contact
(temperature)



Unsupported holding
(weight)



Enclosure
(global shape, volume)



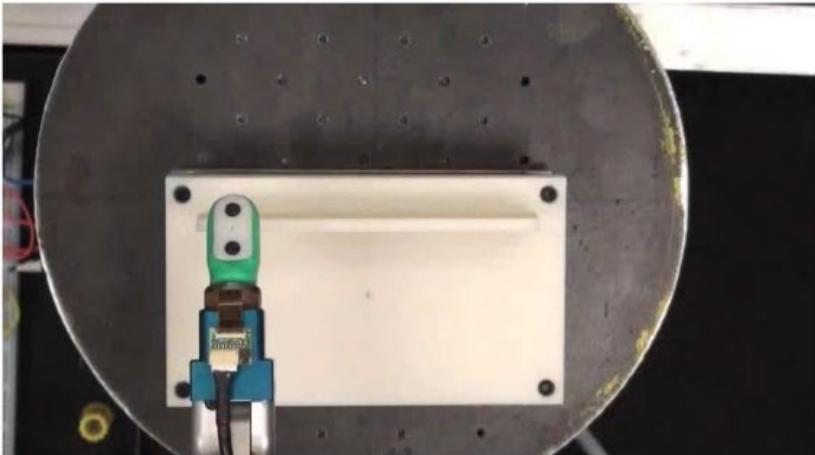
Contour following
(local shape, volume)

Exploratory procedures (EPs) identified from human psychophysics experiments

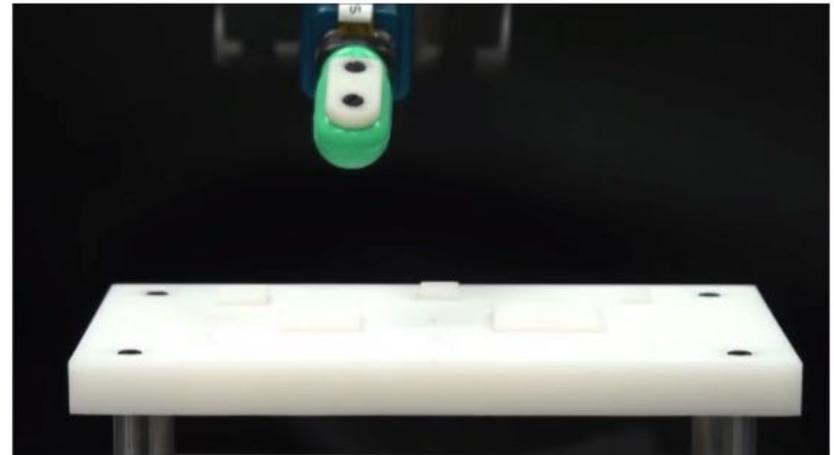
(Lederman and Klatzky, 1987)

Artificial haptic perception

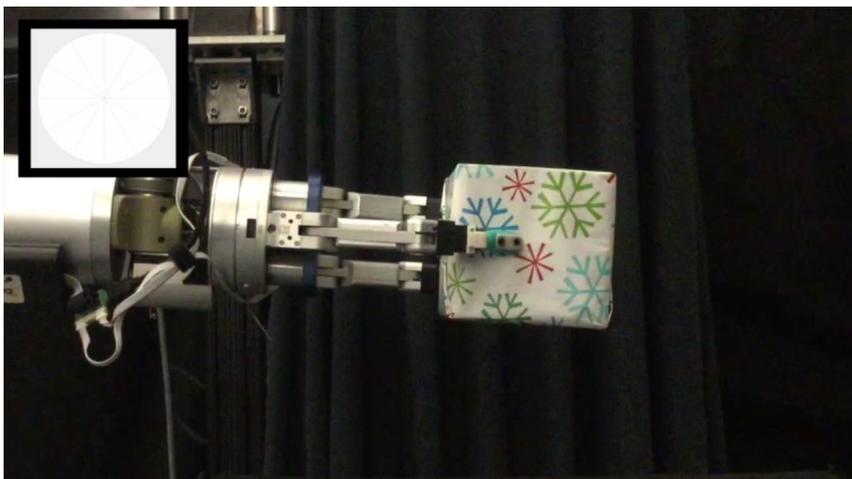
Edge orientation



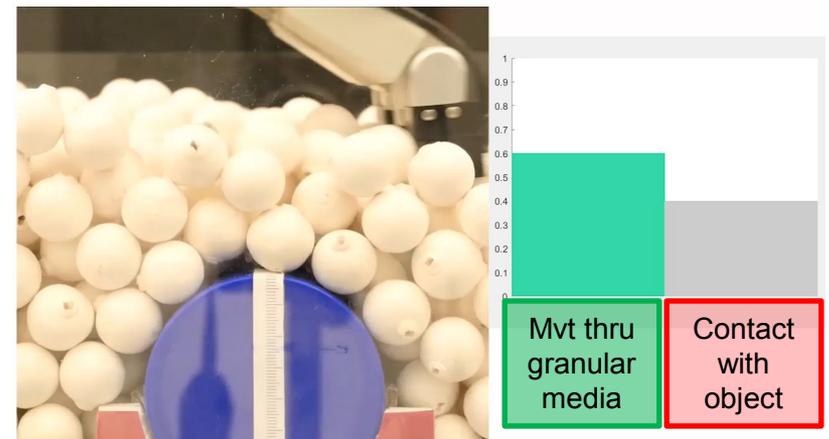
Bump/pit size and shape



Tactile directionality



In granular media



Shown at 1/4 speed

Tactile sensing challenges

- Tactile sensors have **small “apertures”** as compared to vision-based sensors.
 - Many touches are required to build a “tactile image.”
- Tactile sensors **require contact**.
 - Contact force must be controlled.
 - Repeated contact causes sensor wear.
 - Debris may adhere to tactile sensor surfaces.

Potential concepts of operation for REPAIR

- Inspection robot scouts ahead for defects and logs their characteristics and location for a coating robot
(+) Pipe would not have to be cleaned beforehand.
- Inspection robot follows the coating robot and assesses the integrity of the composite coating
- Multiple modalities of touch could be employed.
 - Sensorpad deformation for perceiving local shape
 - Vibration for perceiving smoothness, detecting defects
 - Thermal flux for detecting defects, checking composite curing

Acknowledgments



Jimmy Penaloza



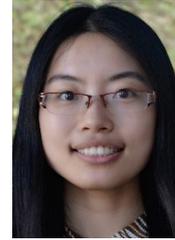
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