Shielded stretchable capacitive force sensors with liquid metal channels

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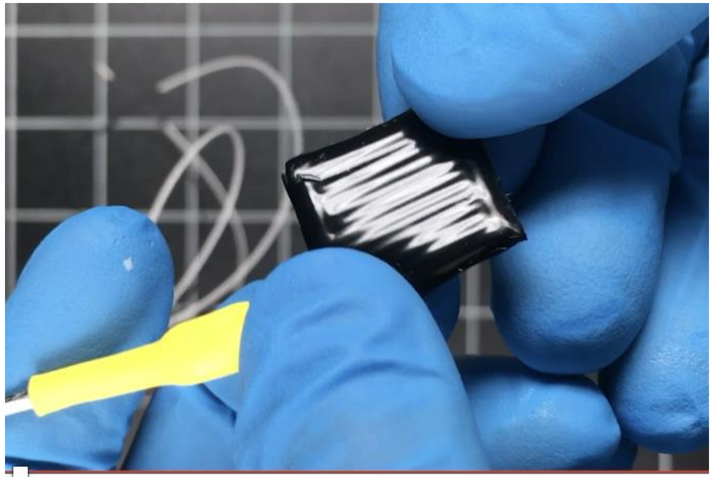
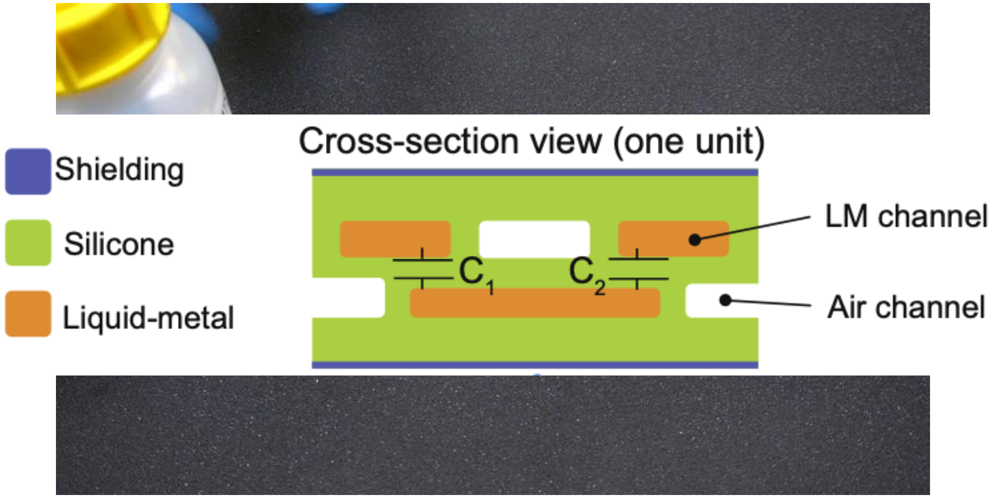
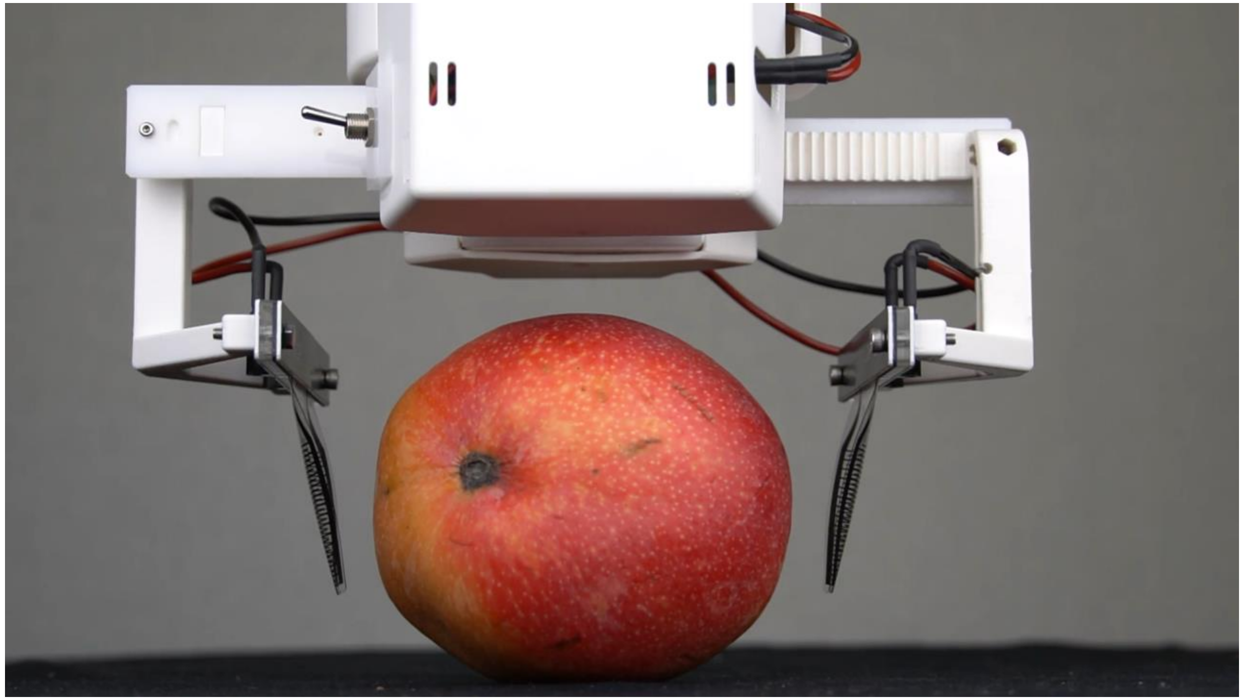




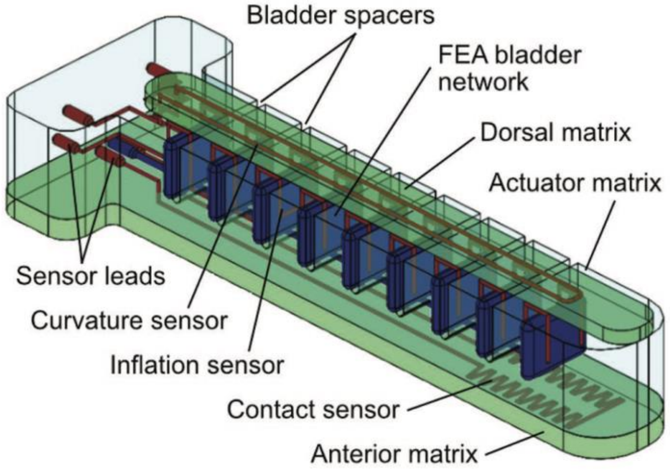
- This project received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869963.

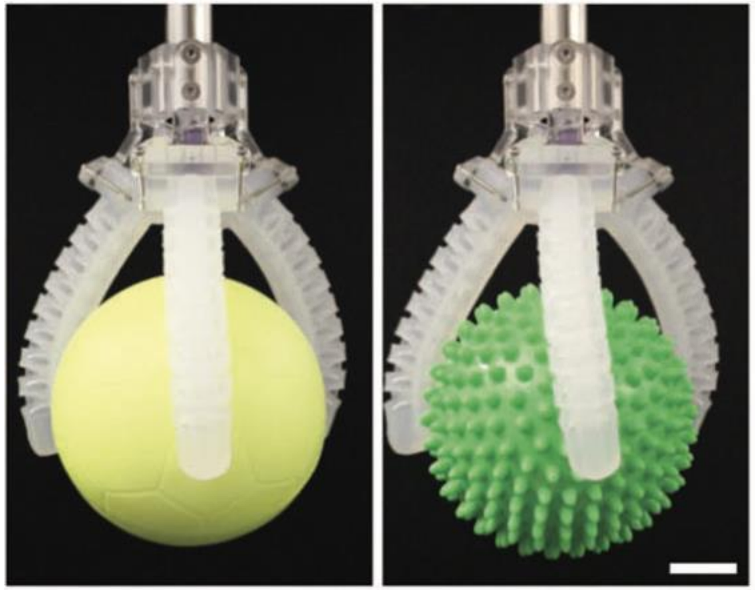
We often need to know normal and shear forces for many robotic or human-machine interactions

but the sensors must be as soft as the gripper / actuator…



V. Cacucciolo, et al, “Peeling in electroadhesion soft grippers,” *Extreme Mechanics Letters* (2022)

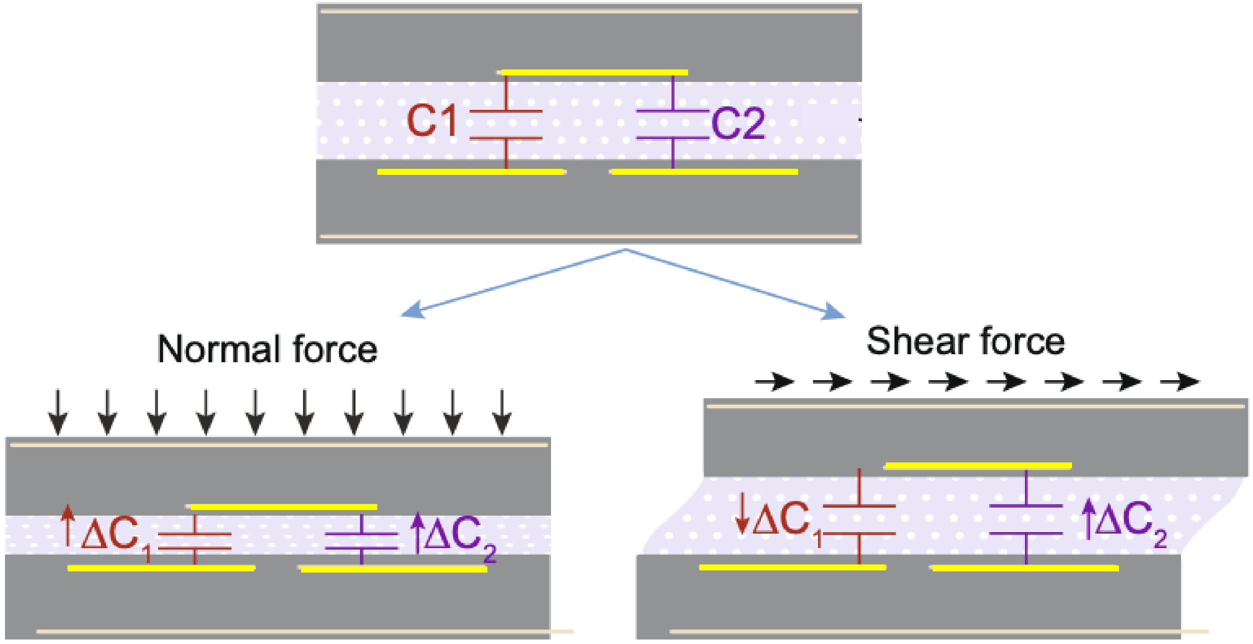


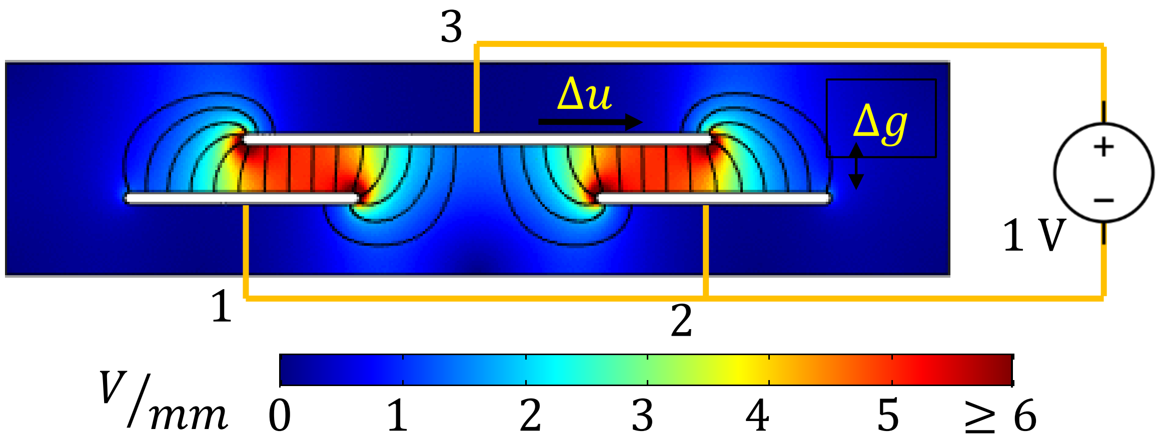


R. L. Truby *et al.*, “Soft Somatosensitive Actuators via Embedded 3D Printing,” *Advanced Materials*, (2018)

Capacitive Force Sensing is widely used

Capacitive sensing:
- low power consumption,
- fast response,
- low hysteresis
- easy fabrication





Shear strain ~ Capacitance difference

$$C_{23} - C_{13}$$

Normal strain ~ Capacitance sum

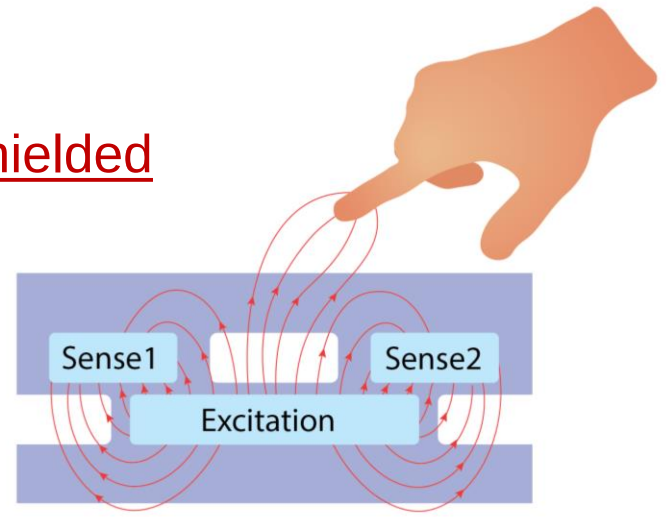
$$C_{23} + C_{13}$$

The capacitive sensor needs to be shielded from external electrical interference

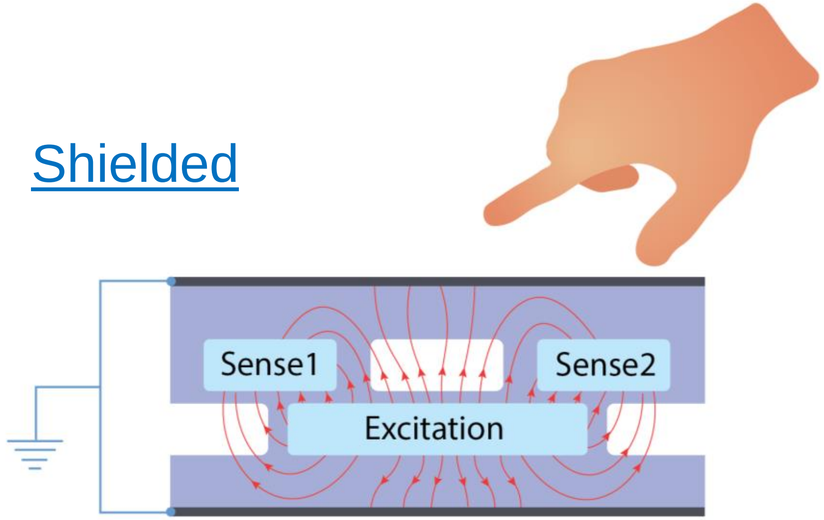
Problem for soft sensors: the **parasitic capacitances between the shield and sensing electrodes** changes when the sensor is deformed.

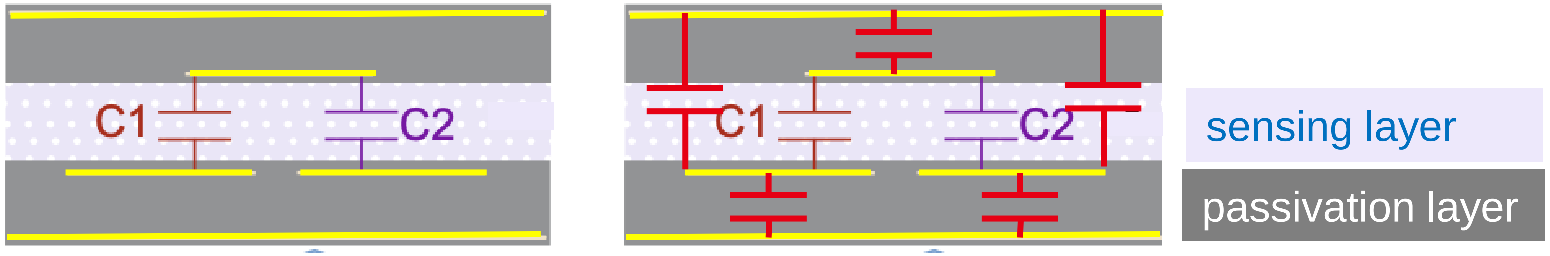
Solution: the **stiffness of the sensing region must be an order of magnitude lower than the stiffness of the encapsulating layer**, so that the parasitic capacitances do not change.

Unshielded

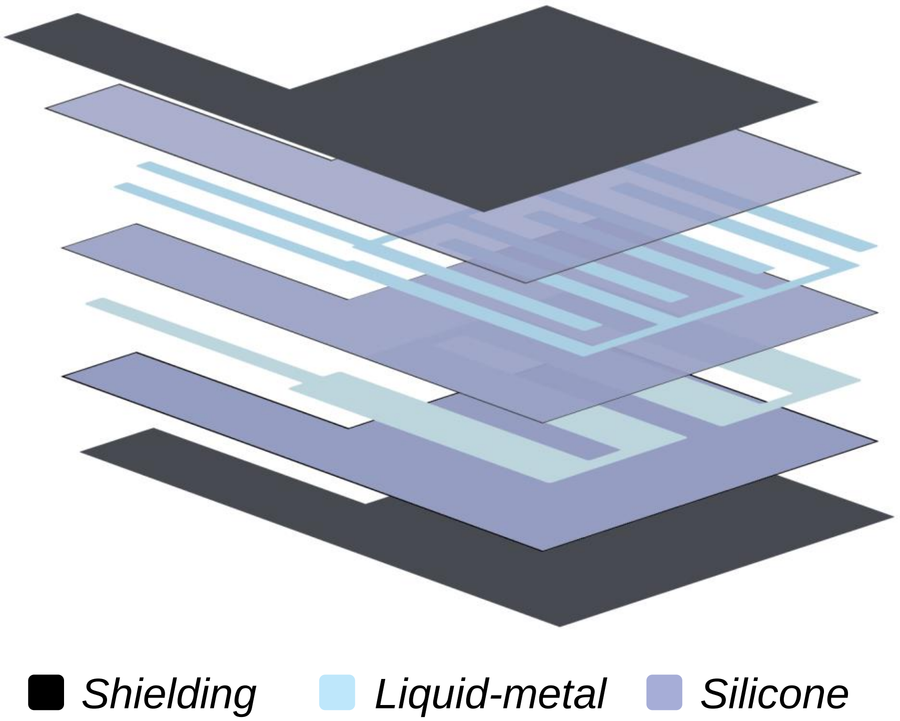


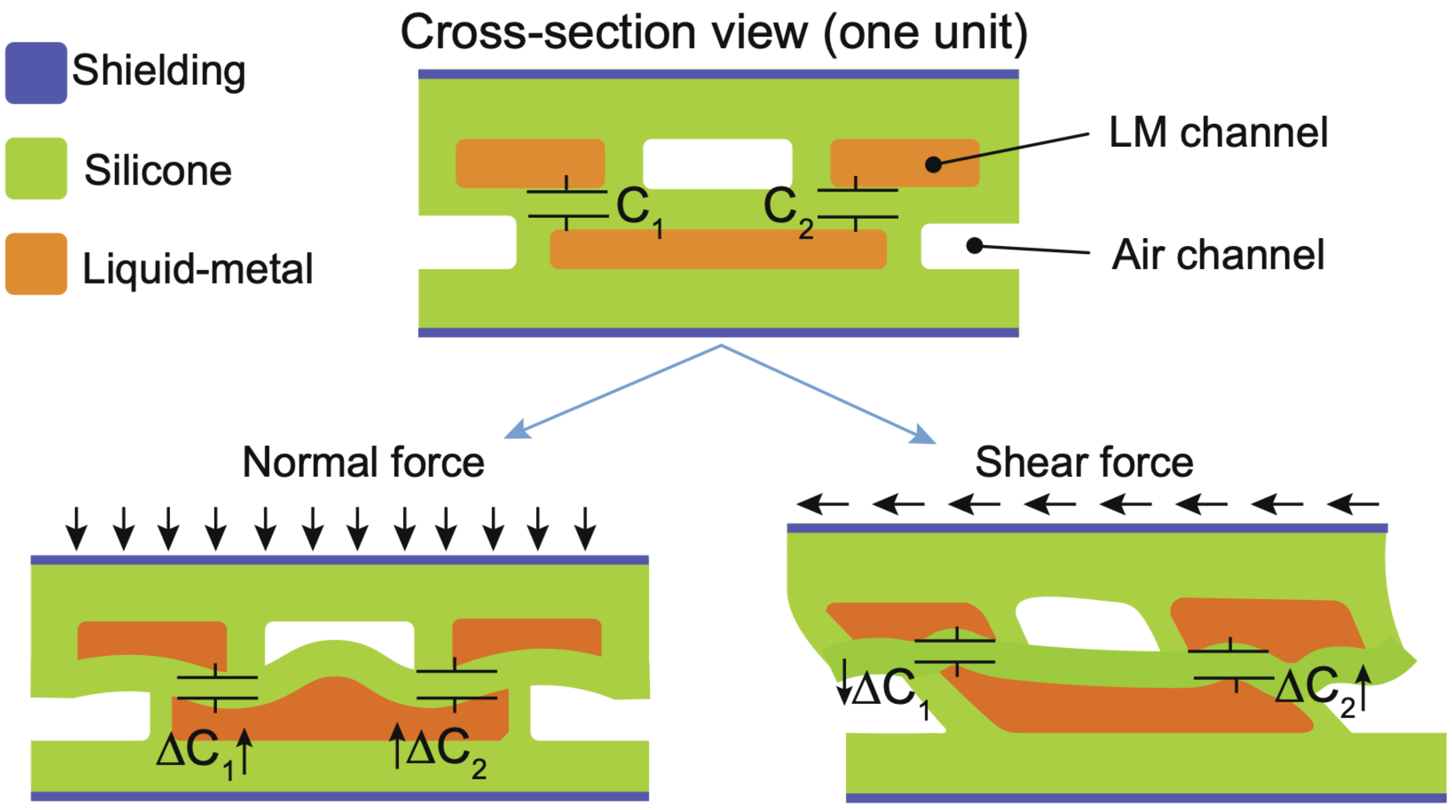
Shielded





We use air channels and liquid electrodes to create a very soft, yet robust, sensing layer





Air channels allow for compression

B. Aksoy et al, "Shielded soft force sensors"
Nature Communications, vol. 13, p. 4649 (2022)

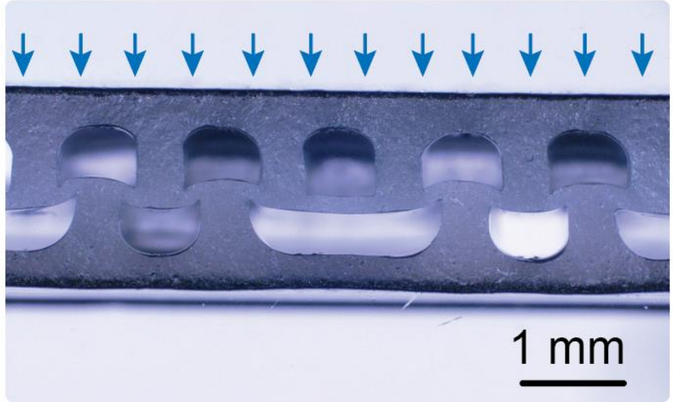
Our Sensors are sensitive to small forces and can tolerate large forces

A fabricated sensor

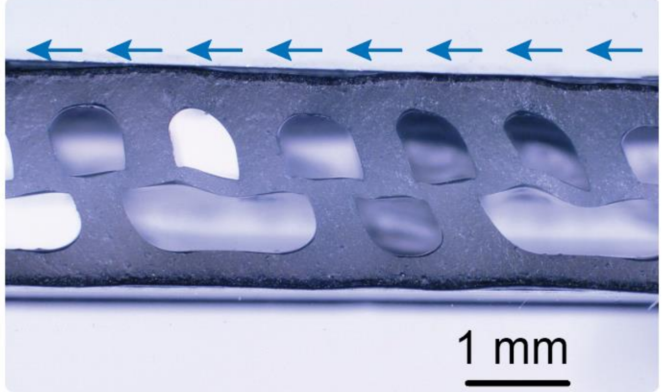
Normal force sensitivity: 2.77 mN/fF
Shear force sensitivity: 0.23 mN/fF
Maximum load: 20 N
*Readout noise: ±0.09 fF

Micrographs taken before liquid-metal filling

Deformation under normal force:

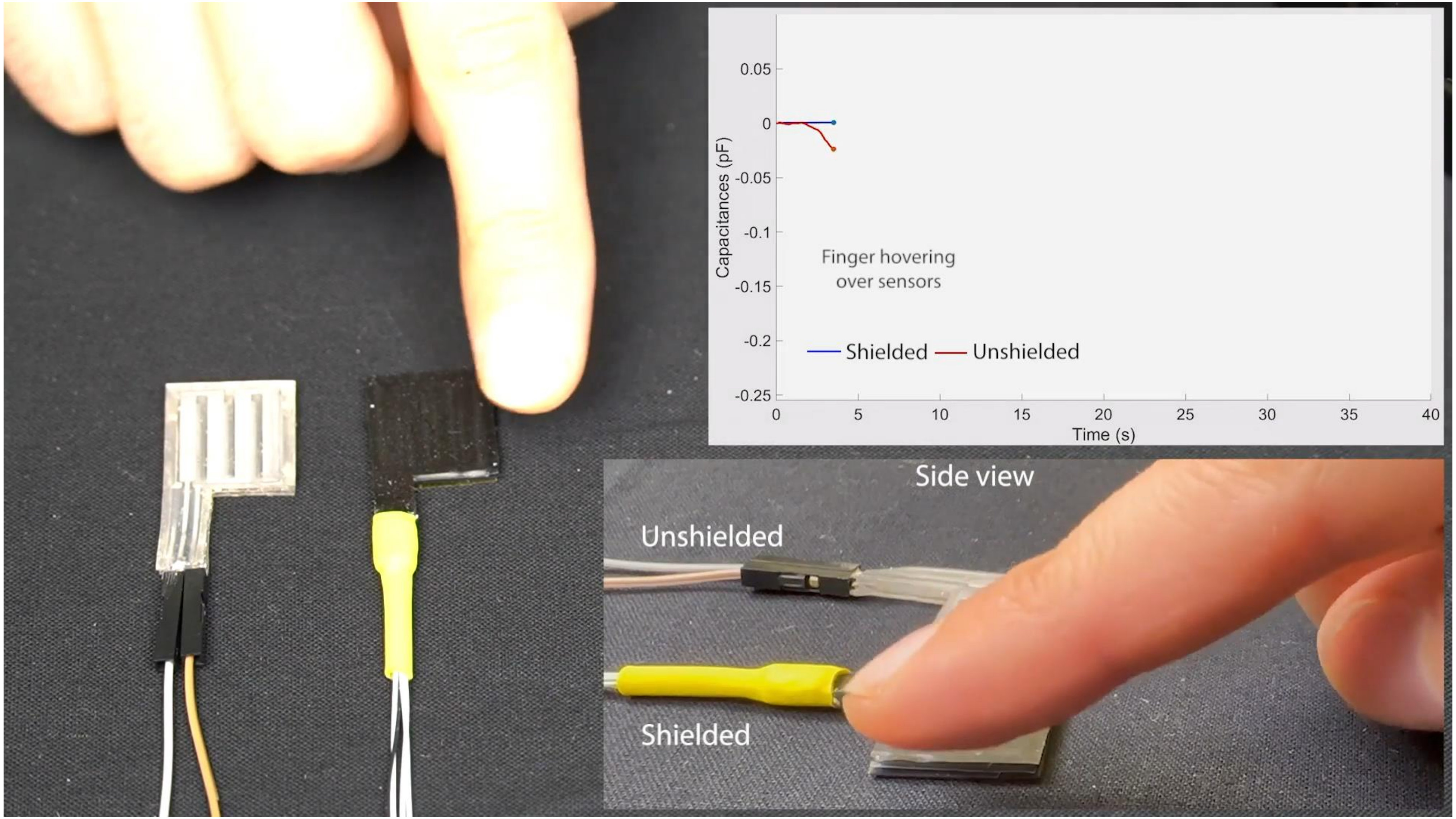


Deformation under shear force:

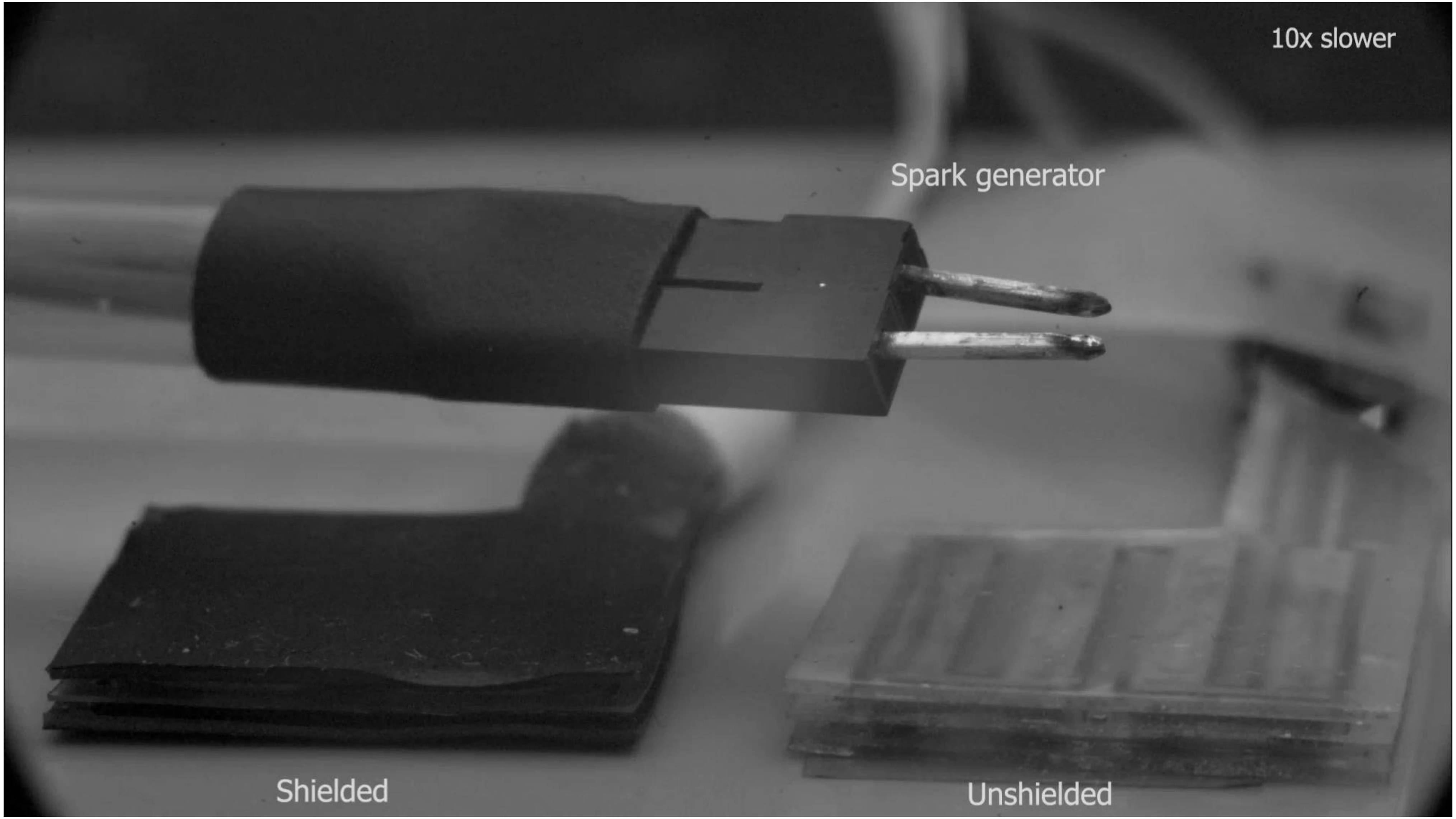


±0.25 mN of normal force and ±0.02 mN of shear force.
2 to 20 N full scale

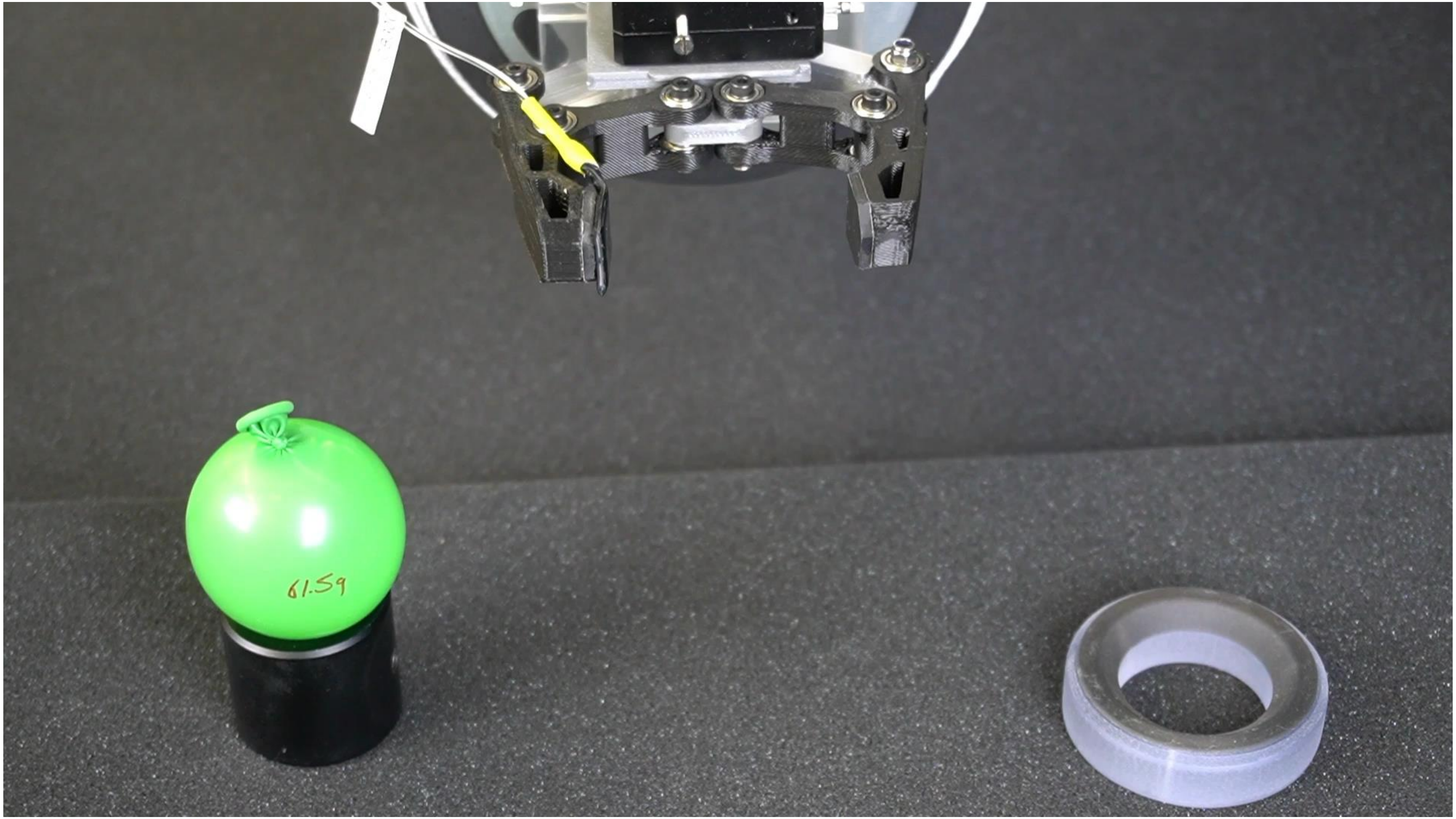
The shielded sensors only react to external forces
The unshielded devices have undesired signal due to proximity



The shielded sensors are immune to sparks!

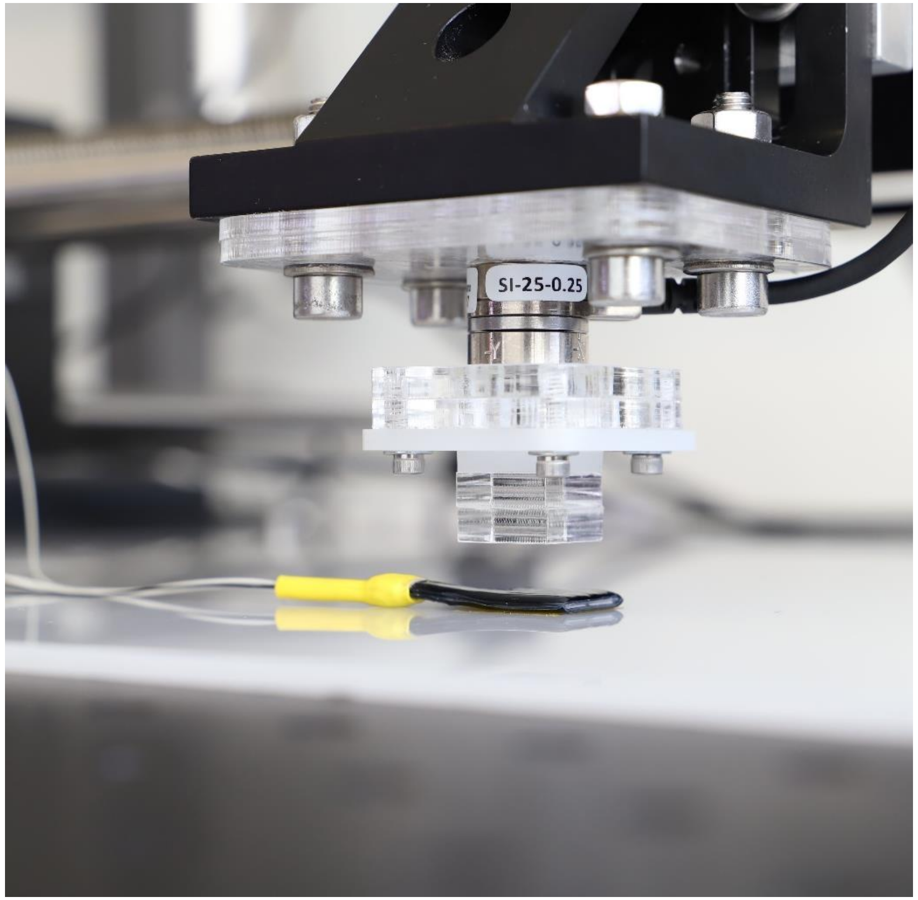


Soft sensor on a gripper: record normal and shear forces while picking up and rotating a water balloon



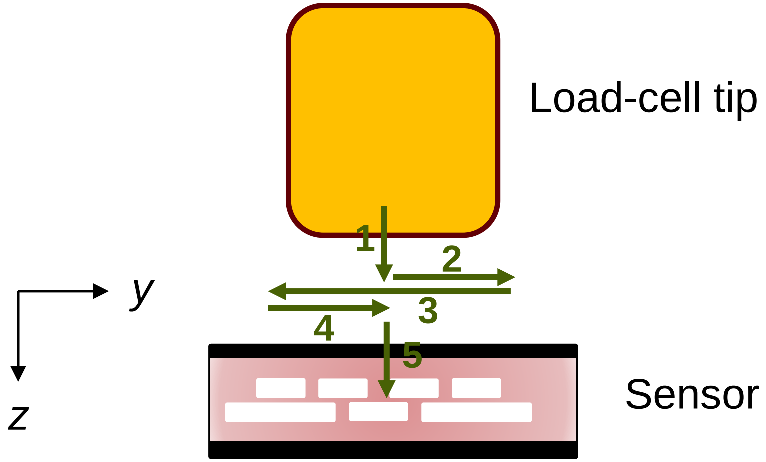
Calibration process is required to determine the two Force values from two measured Capacitance values

Experimental setup for sensor calibration



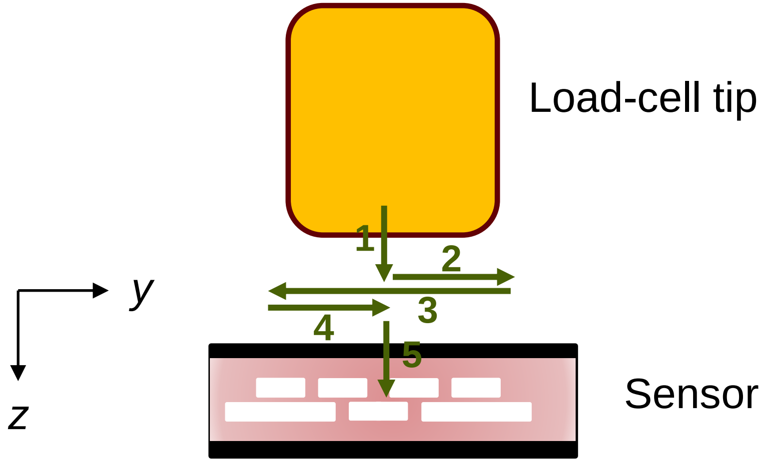
- Loadcell measures the applied normal and shear force
- Capacitance meter measures C1 and C2

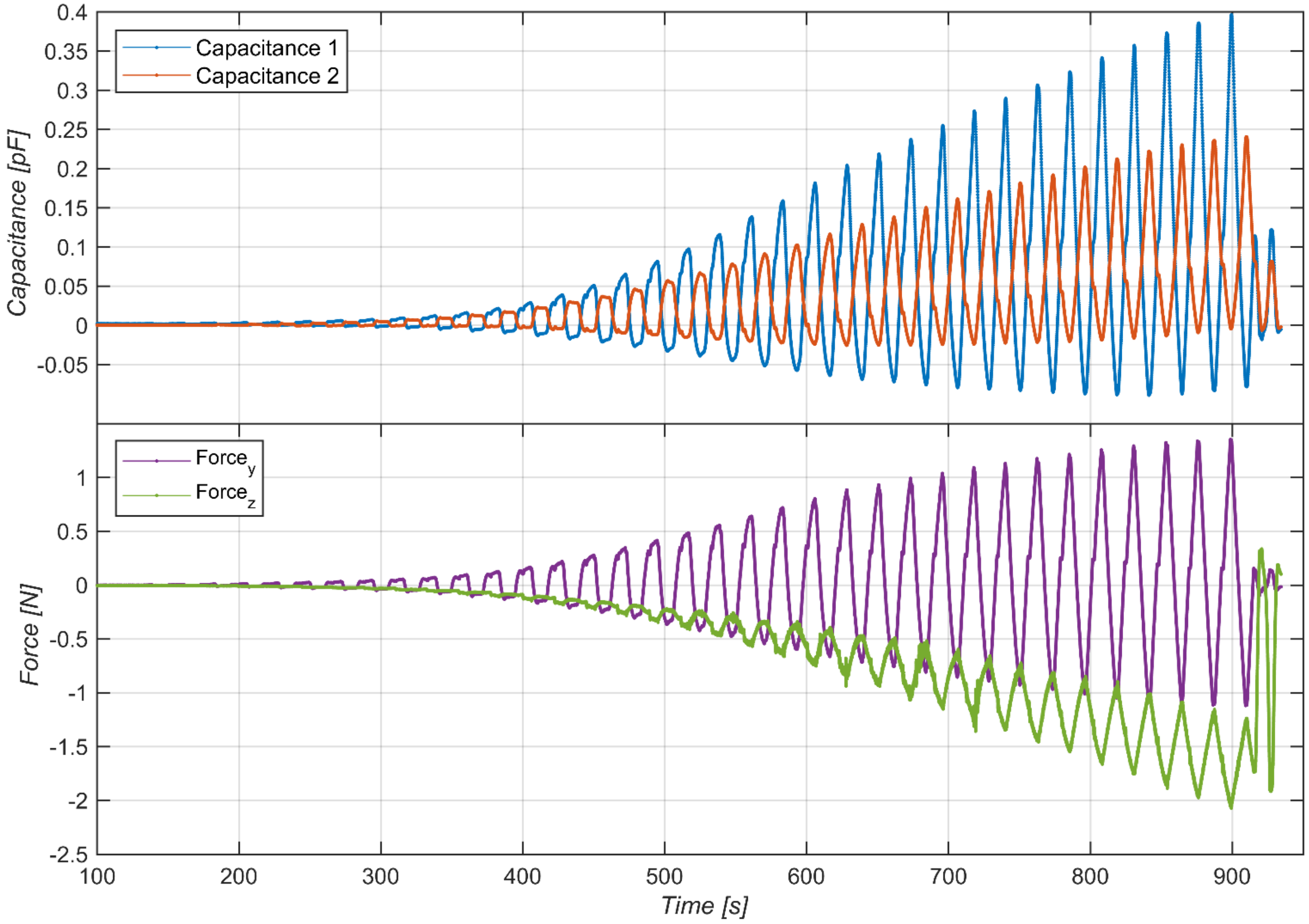
Schematic of the setup & procedure



1. Move in +z direction (Δz = 0.005 mm)
2. Move in +y direction (Δy = 0.25 mm)
3. Move in -y direction (Δy = -0.5 mm)
4. Move in +y direction (Δy = 0.25 mm)
5. Repeat steps 1-4 for 40 times
6. …
7. Move to initial position

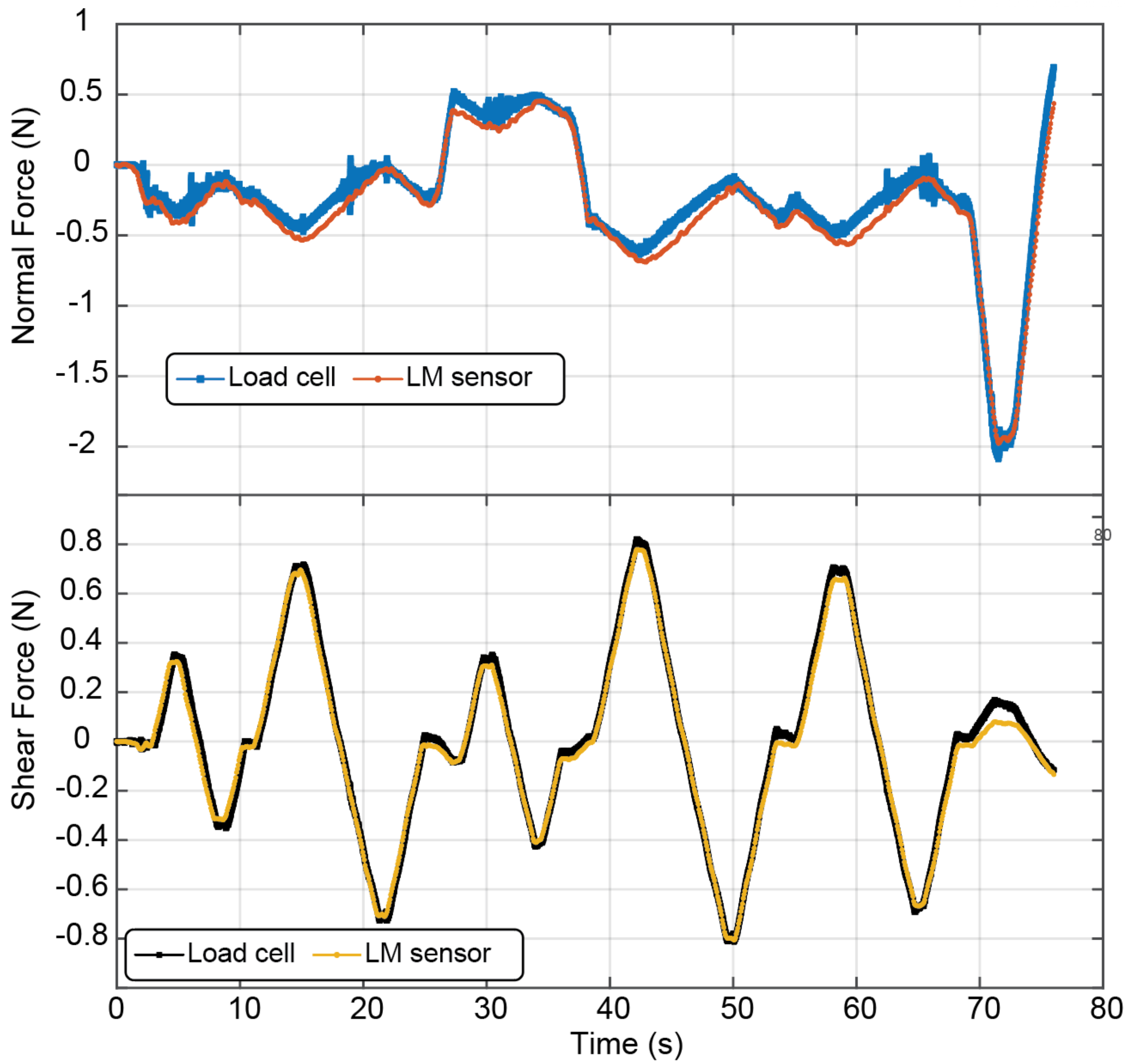
Sensor calibration process





➢ Then fit to determine $F_{normal}(C1,C2)$ and $F_{shear}(C1,C2)$

Excellent agreement between soft sensor and load cell



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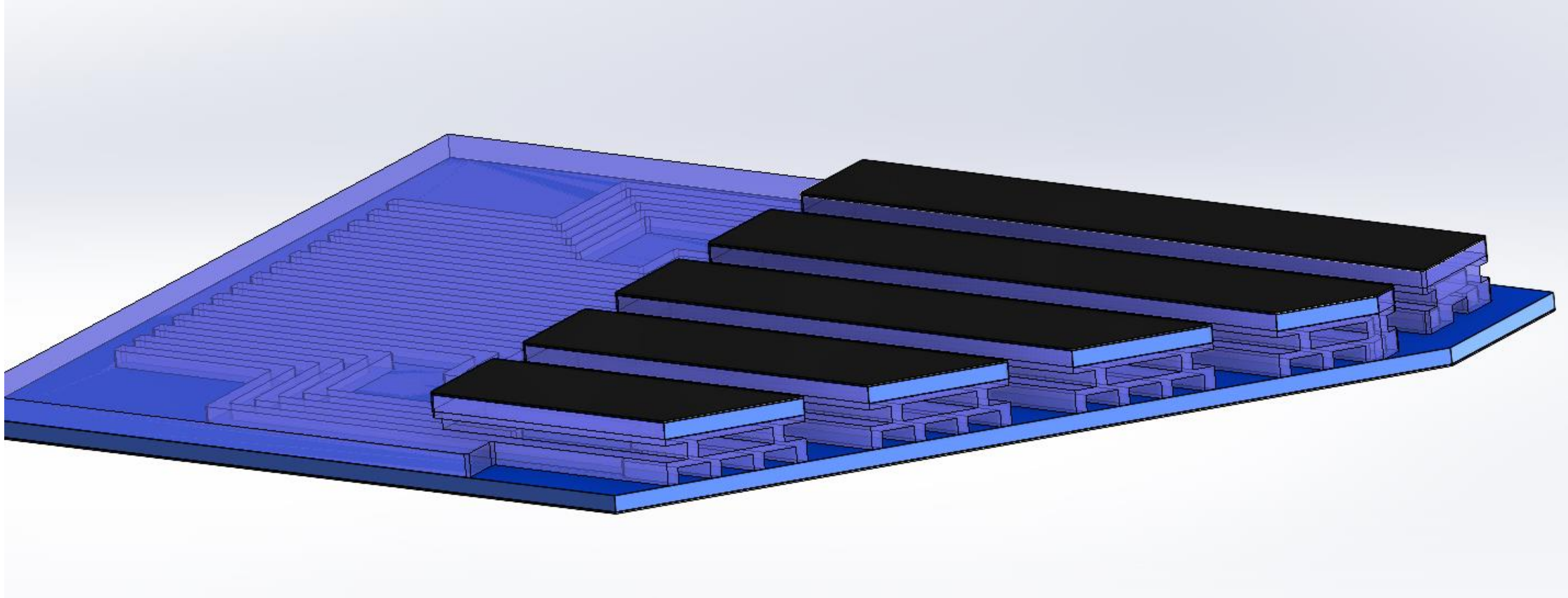
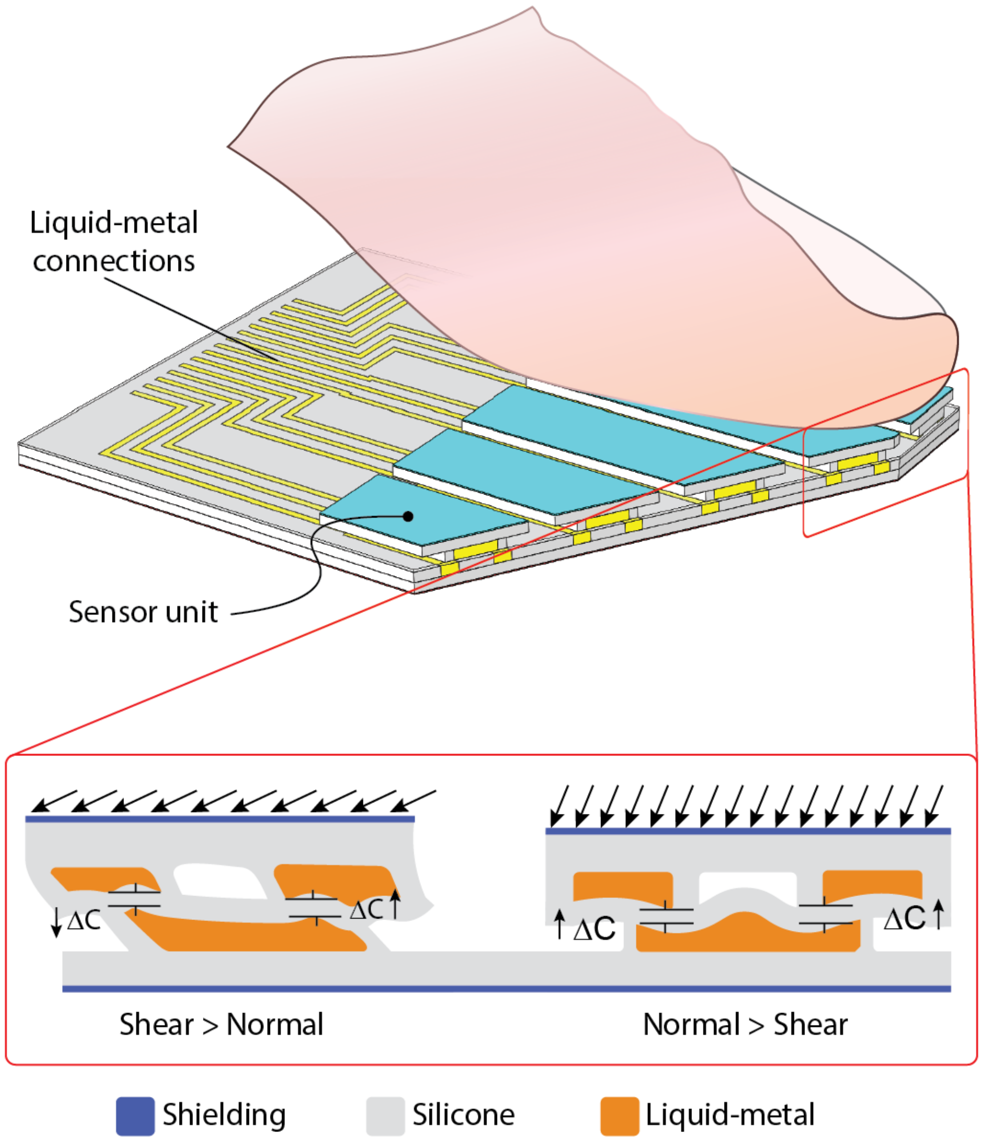
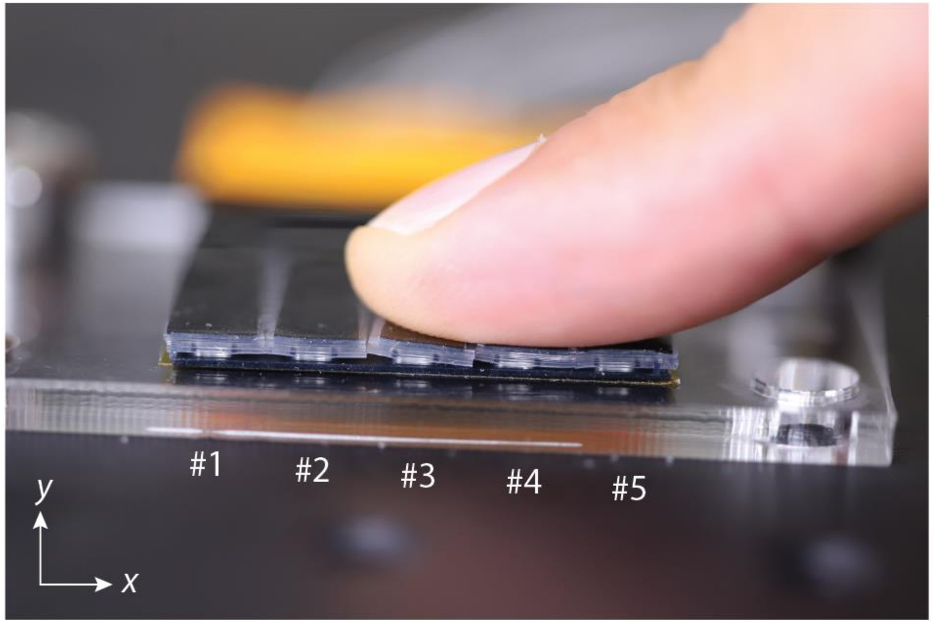
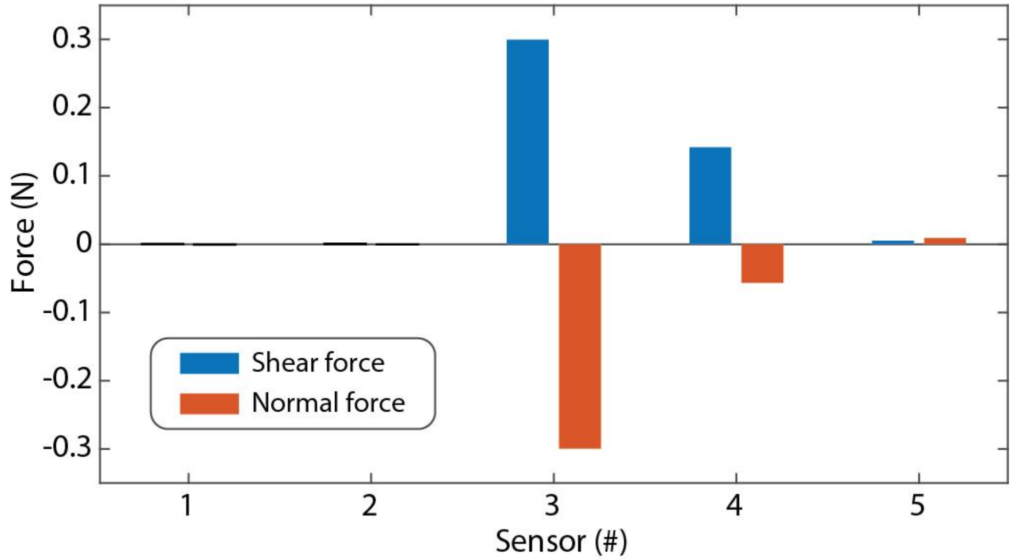
Single sensors are nice, but Arrays allow distributed sensing and advanced slip detection

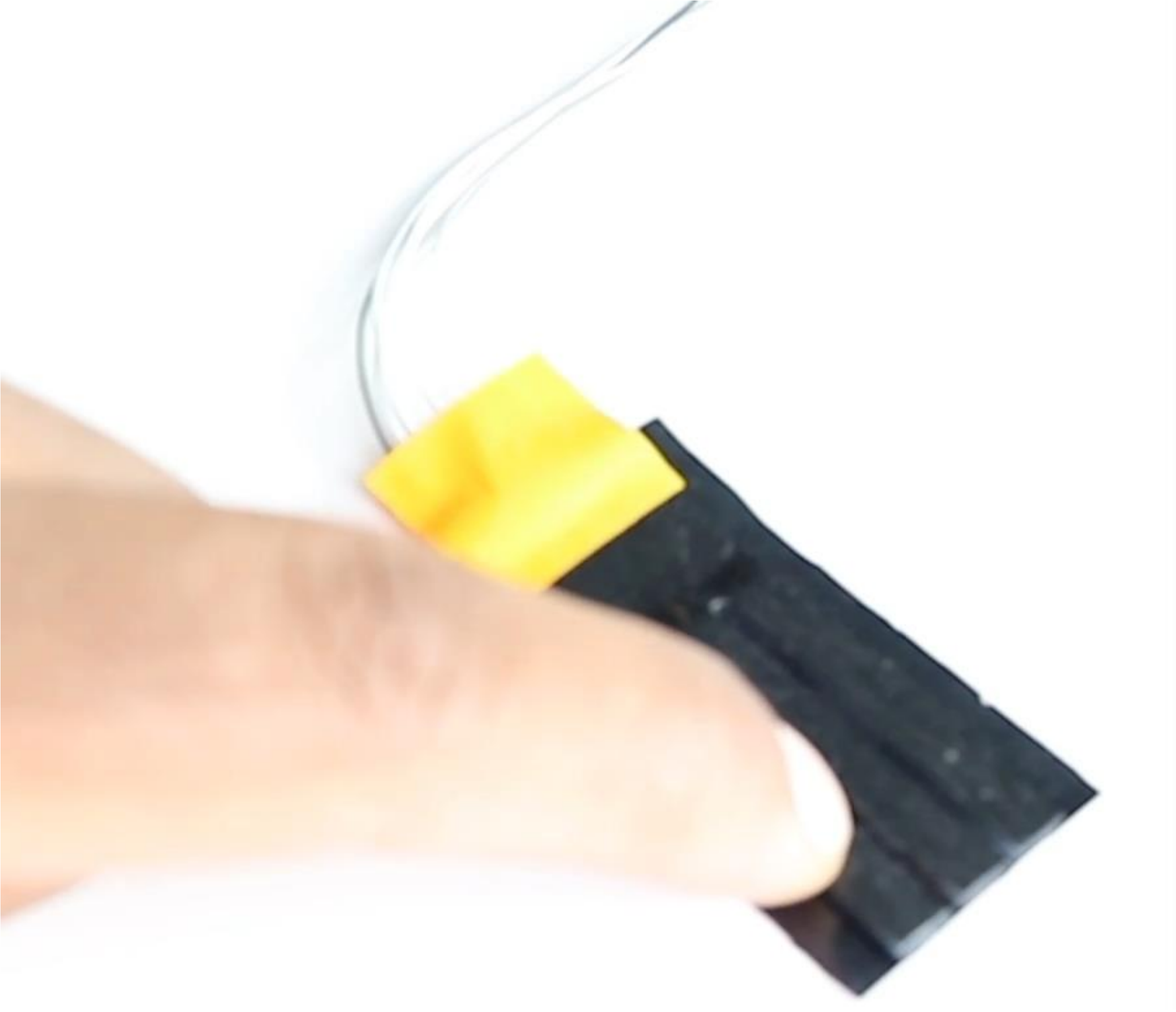


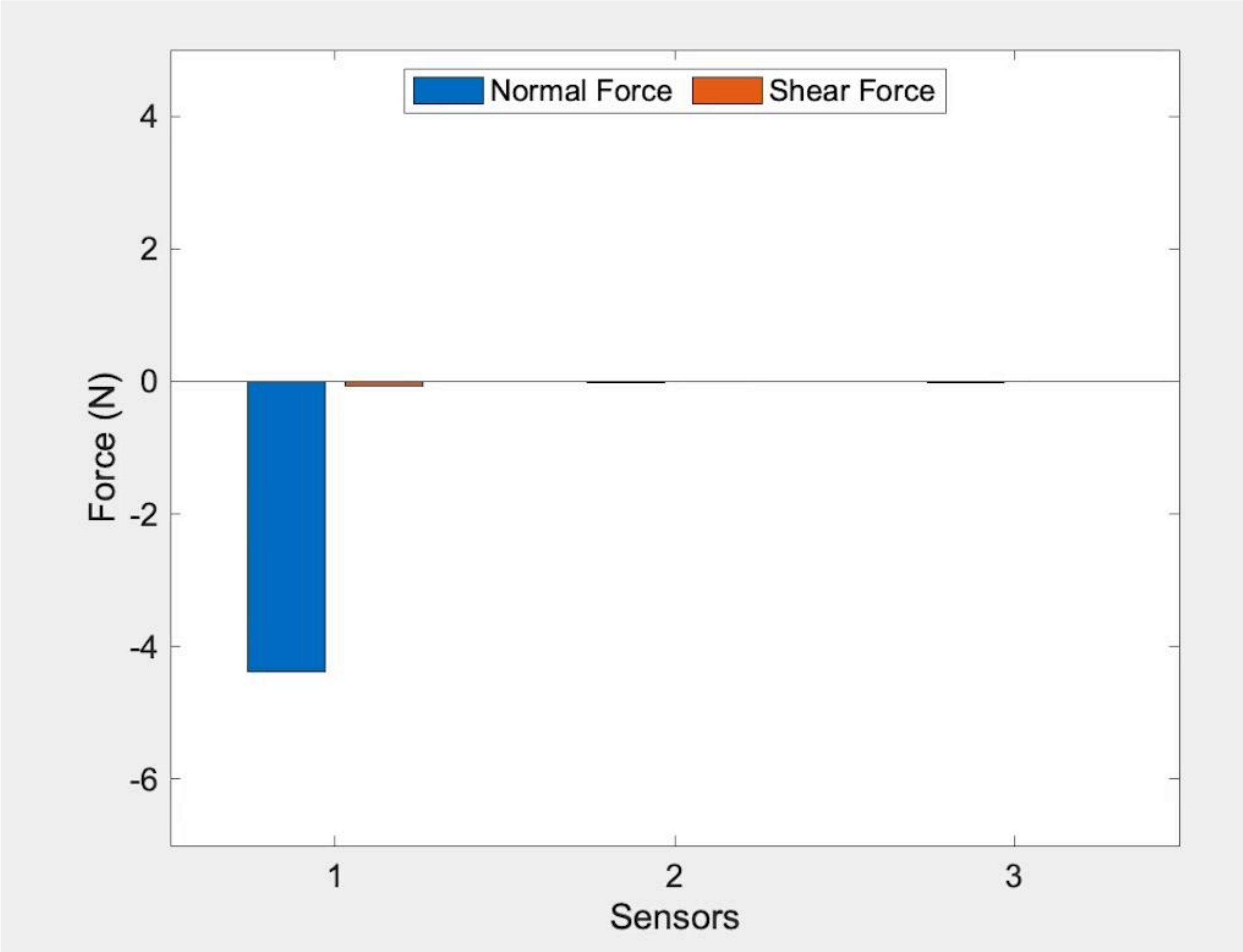
Each unit in a 5x1 array measures both shear and normal forces











Pressing units randomly

Electromechanically decoupled soft sensor array using liquid–metal

Bekir Aksoy, Krishna Manaswi Digumarti, and Herbert Shea

Supplementary Movie 3

EPFL

Summary

- Soft grippers & soft machines need soft force sensors, softer than the gripper

- We developed a way to electrically shield soft sensors to get high ElectroMagnetic immunity, yet robustly and reliably measure simultaneously shear and normal forces

- Only 2 mm thick, 1 MPa stretchable
- Up to 20 N, with sub-mN resolution

- Can easily modify geometry to suit other force ranges, and extend to 2D arrays

EPFL

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MERGING

More info:

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"Shielded soft force sensors"

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Thank you for your attention!

https://www.epfl.ch/labs/lmts/

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