TÉCNICO LISBOA

MEFT
Boosting the Future

Smart fingertip tactile sensors for agrorobotics applications

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Nancy S. Giges, “Smart Robots for Picking Fruit”, American Society of Mechanical Engineers (ASME), May 2013, https://www.asme.org/topics-resources/content/smart-robots-for-picking-fruit

Introduction

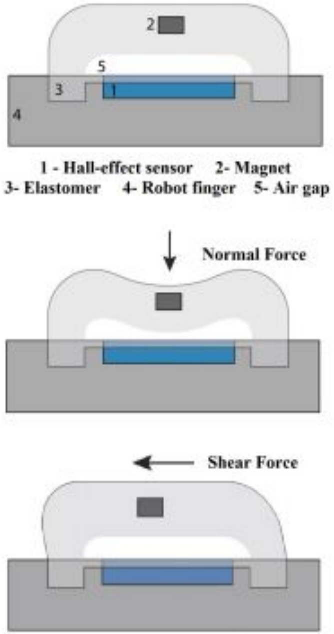
- Effort to introduce automated technologies for **manipulation**, **inspection** and **harvest**
- Quick and cost-effective
- Harvest **without damage**

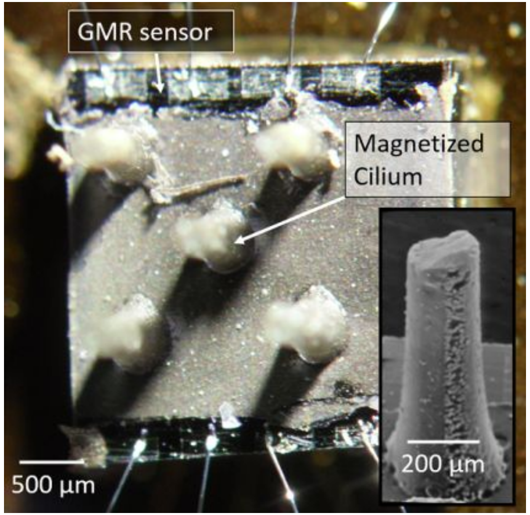
Example of commercial gripper for grape picking

Sensor technologies

Context

- **INESC-MN** and **ISR-Robotics** collaboration work in magnetic tactile sensors





Design scheme of Hall effect (left) and ciliary structure GMR (up) magnetic sensors

Ribeiro, P., Khan, M., Alfadhel, A., Kosel, J., Franco, F., Cardoso, S., Bernardino, A., Schmitz, A., Santos-Victor, J. and Jamone, L., 2017. Bioinspired Ciliary Force Sensor for Robotic Platforms. IEEE Robotics and Automation Letters, 2(2), pp.971-976.
T. Paulino et al., "Low-cost 3-axis soft tactile sensors for the human-friendly robot Vizzy," 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017, pp. 966-971, doi: 10.1109/ICRA.2017.7989118.

Objectives

Instrumentation of a robotic hand

Using tactile sensing technologies
Quick evaluation of the quality of produce

Evaluate strategies;
Develop sensors embedded in elastomers and artificial skin

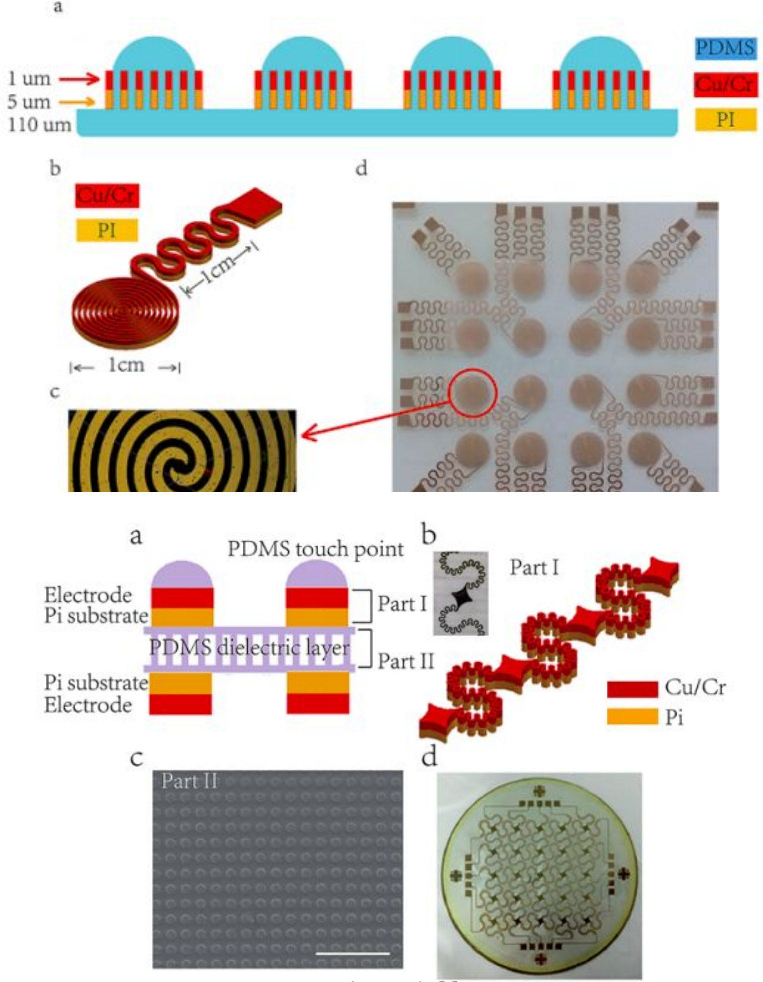
Combine tactile ability with a sensitive perception of texture
at the time of harvest

Tactile sensing transduction techniques

capacitive, piezoresistive, piezoelectric, inductive and optical

Capacitive

- 2 electrodes with dielectric material between them;
- External force changes **distance** between electrodes or **overlapping area** ⇒ change in **capacitance**[1]

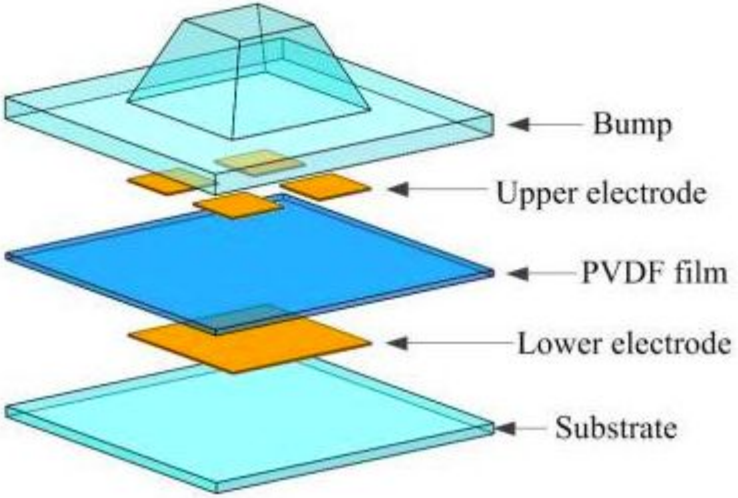


Capacitive sensor with 2 different structures: CIS (Up) and PPS (Down)

Wang, X., Xu, T., Dong, S., Li, S., Yu, L., Guo, W., Jin, H., Luo, J., Wu, Z. and King, J., 2017. Development of a flexible and stretchable tactile sensor array with two different structures for robotic hand application. RSC Adv., 7(76), pp.48461-48465.
[1]Chi C, Sun X, Xue N, Li T, Liu C. Recent Progress in Technologies for Tactile Sensors. Sensors (Basel). 2018;18(4):948. Published 2018 Mar 22. doi:10.3390/s18040948

Piezoelectric

- Piezoelectric materials (PVDF, ceramics): **generate a potential** proportional to external forces[1]
- Piezoelectric parallel plate capacitor[2]

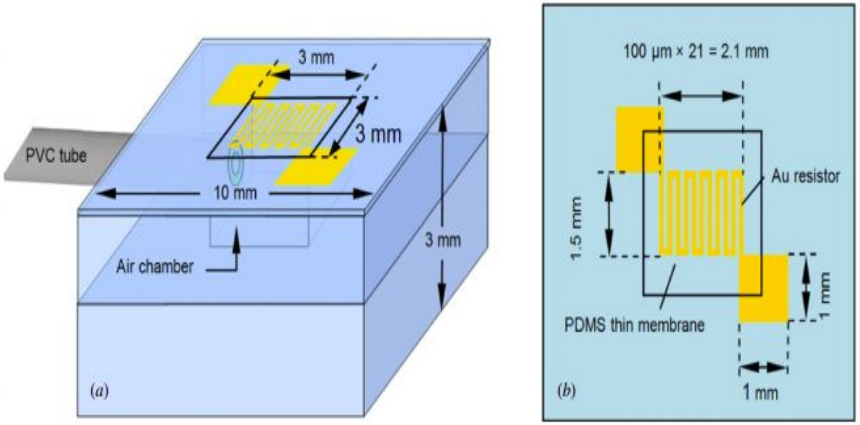


Piezoelectric sensor fabrication layers

Yu, P., Liu, W., Gu, C., Cheng, X. and Fu, X., 2016. Flexible Piezoelectric Tactile Sensor Array for Dynamic Three-Axis Force Measurement. Sensors, 16(6), p.819.
[1]Chi C, Sun X, Xue N, Li T, Liu C. Recent Progress in Technologies for Tactile Sensors. Sensors (Basel). 2018;18(4):948. Published 2018 Mar 22. doi:10.3390/s18040948
[2]Girão P, Ramos P, Postolache O, Miguel Dias Pereira J. Tactile sensors for robotic applications. Measurement. 2013;46(3):1257-1271. doi:10.1016/j.measurement.2012.11.015

Piezoresistive

- Piezoresistive material (elastomer, conductive rubber) - placed between or in touch with 2 electrodes - **changes resistance** when an external force is applied [2]



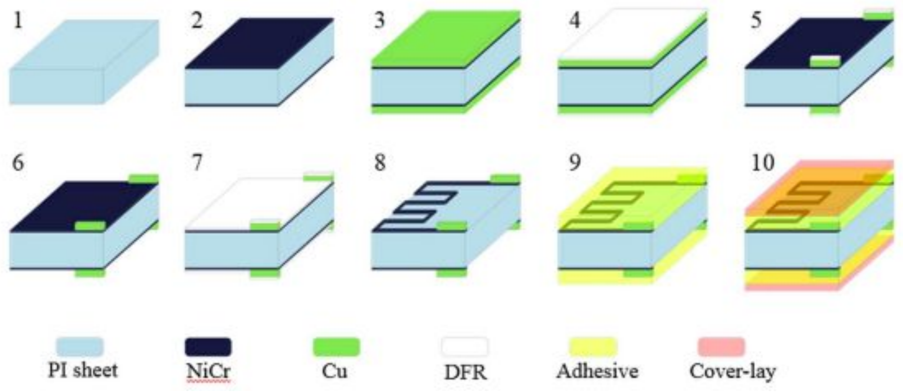
Schematics of PDMS-based piezoresistive sensor

Liu X, Zhu Y, Nomani M, Wen X, Hsia T, Koley G. A highly sensitive pressure sensor using a Au-patterned polydimethylsiloxane membrane for biosensing applications. Journal of Micromechanics and Microengineering. 2013;23(2):025022. doi:10.1088/0960-1317/23/2/025022

[2]Girão P, Ramos P, Postolache O, Miguel Dias Pereira J. Tactile sensors for robotic applications. Measurement. 2013;46(3):1257-1271. doi:10.1016/j.measurement.2012.11.015

Strain Gauges

- Resistive based, zig zag **patterned metallic foil** on flexible material;
- **Resistance** changes according to the applied force that stretches or compresses the gauge[1]



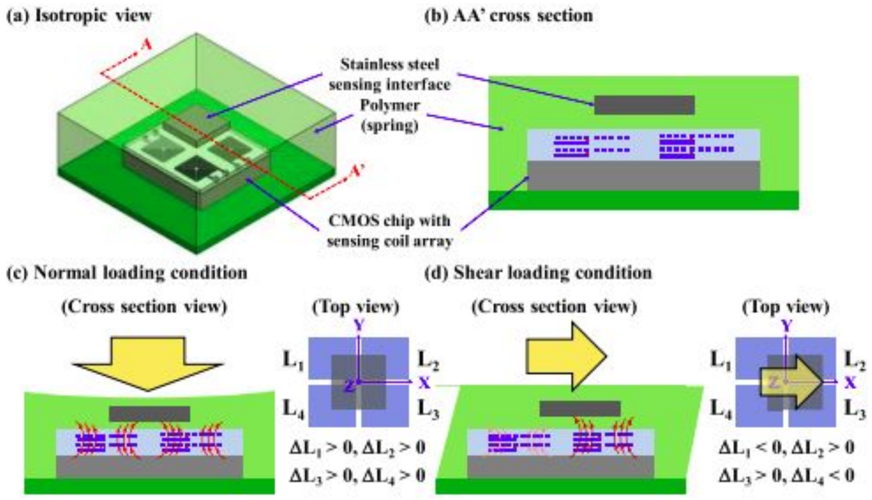
Example fabrication process of Strain Gauge

Kwak, Y., Kim, W., Park, K., Kim, K. and Seo, S., 2017. Flexible heartbeat sensor for wearable device. Biosensors and Bioelectronics, 94, pp.250-255.

[1]Chi C, Sun X, Xue N, Li T, Liu C. Recent Progress in Technologies for Tactile Sensors. Sensors (Basel). 2018;18(4):948. Published 2018 Mar 22. doi:10.3390/s18040948

Inductive

- Measure changes in magnetic induction of coupled coils/ uncoiled conductor when affected by an external force
- By applying an external force one **modulates the inductance** sensed in the sensing element[3]

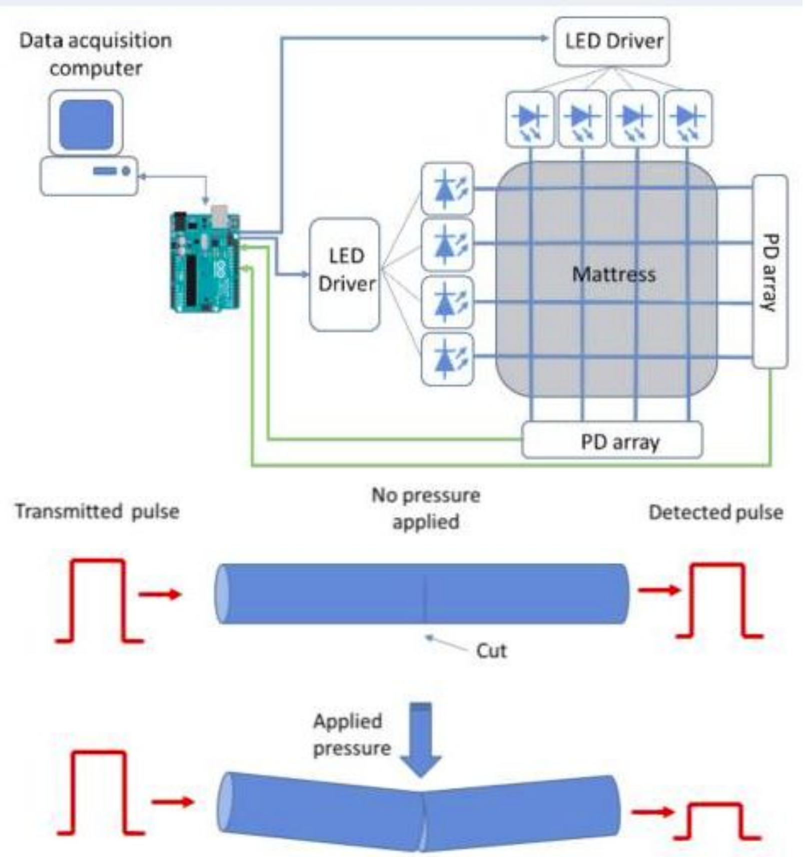


Schematic and principle of operation of Inductive tactile sensor

Yeh, S. and Fang, W., 2019. Inductive Micro Tri-Axial Tactile Sensor Using a CMOS Chip With a Coil Array. IEEE Electron Device Letters, 40(4), pp.620-623.
[3]Tiwana M, Redmond S, Lovell N. A review of tactile sensing technologies with applications in biomedical engineering. Sensors and Actuators A: Physical. 2012;179:17-31. doi:10.1016/j.sna.2012.02.051

Optical

- Transmitting medium is bent by applied force ⇒ Measure change in light intensity[1]



Optical sensor: application (up) and principle of operation (down)

Sartiano, D. and Sales, S., 2017. Low Cost Plastic Optical Fiber Pressure Sensor Embedded in Mattress for Vital Signal Monitoring. Sensors, 17(12), p.2900.

[1]Chi C, Sun X, Xue N, Li T, Liu C. Recent Progress in Technologies for Tactile Sensors. Sensors (Basel). 2018;18(4):948. Published 2018 Mar 22. doi:10.3390/s18040948

Relative advantages

Capacitive	Piezoelectric	Piezoresistive
High **sensitivity** High spatial resolution Good **dynamic range** Independence of temperature	High **frequency response** High dynamic range High sensitivity	High spatial resolution Low cost **Simple electronics** Low susceptibility to noise
Strain Gauges	**Inductive**	**Optical**
Good sensing range High sensitivity **Low cost**	**Linear output** High dynamic range High sensitivity	**Reliable** Large sensing range High repeatability High spatial resolution **Immunity to EMI**

Chi C, Sun X, Xue N, Li T, Liu C. Recent Progress in Technologies for Tactile Sensors. Sensors (Basel). 2018;18(4):948. Published 2018 Mar 22. doi:10.3390/s18040948

Girão P, Ramos P, Postolache O, Miguel Dias Pereira J. Tactile sensors for robotic applications. Measurement. 2013;46(3):1257-1271. doi:10.1016/j.measurement.2012.11.015

Tiwana M, Redmond S, Lovell N. A review of tactile sensing technologies with applications in biomedical engineering. Sensors and Actuators A: Physical. 2012;179:17-31. doi:10.1016/j.sna.2012.02.051

Relative disadvantages

Capacitive

Susceptible to **noise**
Cross-talk
Stray capacitance
Complexity of electronics

Piezoelectric

Poor spatial resolution
Only dynamic sensing

Piezoresistive

Hysteresis
High power consumption
Low repeatability

Strain Gauges

Hysteresis
Nonlinear response
Susceptible to temperature
Susceptible to humidity
Complex design

Inductive

Poor reliability
Low frequency response
High power consumption
Stray capacitance

Optical

Bulky
Non-conformable
Processing power requirements

Chi C, Sun X, Xue N, Li T, Liu C. Recent Progress in Technologies for Tactile Sensors. Sensors (Basel). 2018;18(4):948. Published 2018 Mar 22. doi:10.3390/s18040948

Girão P, Ramos P, Postolache O, Miguel Dias Pereira J. Tactile sensors for robotic applications. Measurement. 2013;46(3):1257-1271. doi:10.1016/j.measurement.2012.11.015

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Timeline

September
Decision: technology, materials, design.

October/ November
Design and fabrication of the tactile sensor.

December -mid January
Calibration and testing.

mid January - February
Data acquisition and ML analysis; Discussion of results.

March- mid May
Writing and delivery of the dissertation.

References

[1] Chi C, Sun X, Xue N, Li T, Liu C. Recent Progress in Technologies for Tactile Sensors. Sensors (Basel). 2018;18(4):948. Published 2018 Mar 22. doi:10.3390/s18040948

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[6] Liu X, Zhu Y, Nomani M, Wen X, Hsia T, Koley G. A highly sensitive pressure sensor using a Au-patterned polydimethylsiloxane membrane for biosensing applications. Journal of Micromechanics and Microengineering. 2013;23(2):025022. doi:10.1088/0960-1317/23/2/025022

[7] Kwak, Y., Kim, W., Park, K., Kim, K. and Seo, S., 2017. Flexible heartbeat sensor for wearable device. Biosensors and Bioelectronics, 94, pp.250-255.

[8] Yeh, S. and Fang, W., 2019. Inductive Micro Tri-Axial Tactile Sensor Using a CMOS Chip With a Coil Array. IEEE Electron Device Letters, 40(4), pp.620-623.

[9] Sartiano, D. and Sales, S., 2017. Low Cost Plastic Optical Fiber Pressure Sensor Embedded in Mattress for Vital Signal Monitoring. Sensors, 17(12), p.2900.

[10]Nancy S. Giges, “Smart Robots for Picking Fruit”, American Society of Mechanical Engineers (ASME), May 2013, https://www.asme.org/topics-resources/content/smart-robots-for-picking-fruit