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Piezoresistive Pressure Sensor Array for Robotic Skin

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NEXT GEN SYSTEMS
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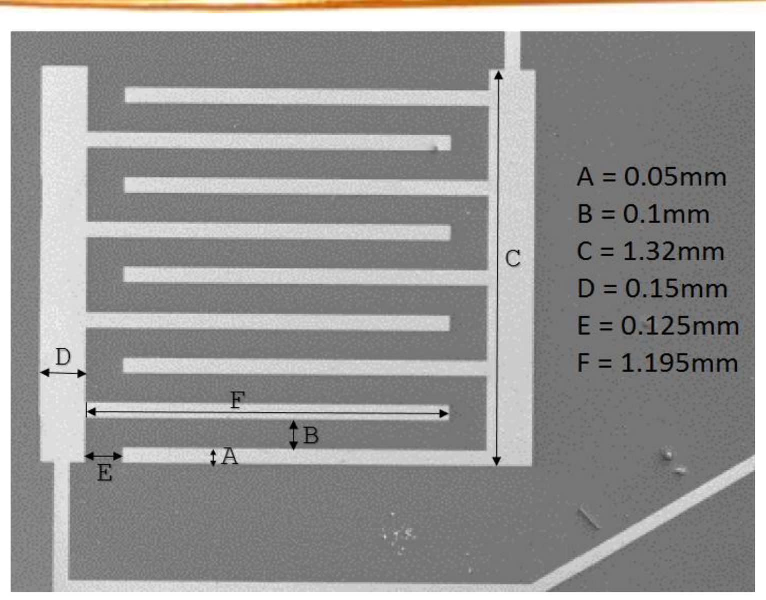
Background

Robots can achieve levels of precision and efficiency well beyond any human capabilities. This is true especially when they operate in a well-structured environments such as factories, and warehouses. Future robots will need to operate in less structured and highly dynamic environments such as homes and hospitals. In these environments, robots will need to share workspaces with humans, and even interact physically. To enhance robot tactile perception capabilities, we are developing whole body robot skins fitted with multi-modal sensors such as pressure and temperature. In this posted we describe efforts to fabricate, integrate and test pressure sensor arrays on flexible substrates.

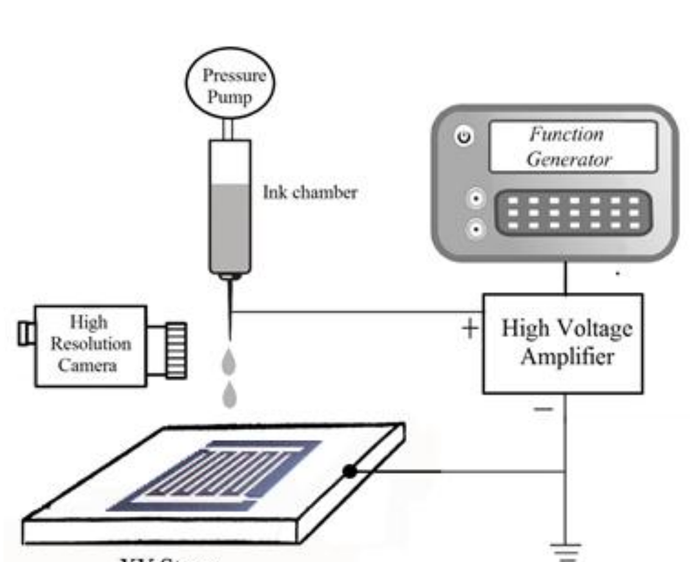
Sensor Fabrication

The substrate of our sensors are fabricated using lithography, deposition and lift-off to make conductive traces. It has 16 interdigitated electrode structures with micron-scale feature on a flexible Kapton sheet. The entire sensing area has a dimension of 15.806mm by 14.58mm.



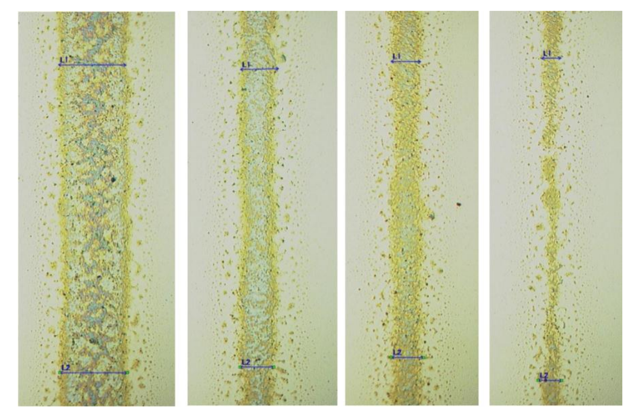
EHD Printing Process

ElectroHydroDynamic (EHD) printing creates an electric field to dispense fluid out of a nozzle. When pressure is applied to the ink chamber, fluid meniscus forms at the nozzle tip. The high voltage electric field is then applied between the nozzle and the ground that is connected with the substrate. The combination of pressure and electric field induces ink-jetting onto the substrate. We used a piezoresistive material, poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) with Dimethyl sulfoxide (DMSO) with the ratio of 1:3 as ink.



Printing Parameters

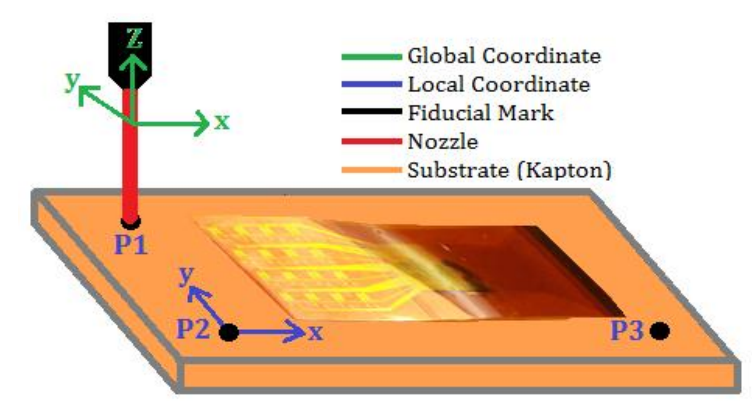
Pressure (kPa)	Distance b/w nozzle and substrate (µm)	DC voltage (V)	Speed (mm/min)
0.15	600	1000	50
0.15	700	1000	150
0.25	600	1600	300
0.50	700	1600	500
1	700	1800	50
1	800	1800	50

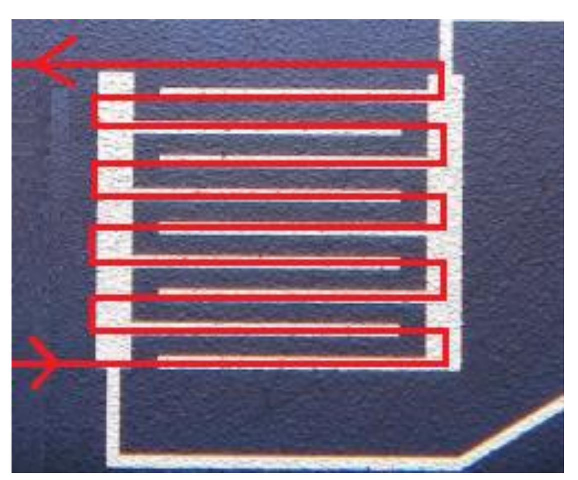


There are four printing parameters that need to be investigated: the applied voltage, pressure, nozzle travel speed and distance between nozzle and substrate. The sample straight lines were printed on gold plates and were examined under a Digital Microscope. Based on the visual feedback, we choose 800µm distance between nozzle tip and substrate, 1.8kV, 1kPa pressure with 3mm/s nozzle travel speed.

System Calibration & Printing Trajectory

A kinematics identification technique was adapted from [1] in order to map the sensor's local coordinate system with respect to global a coordinate system of the print head XYZ stages.

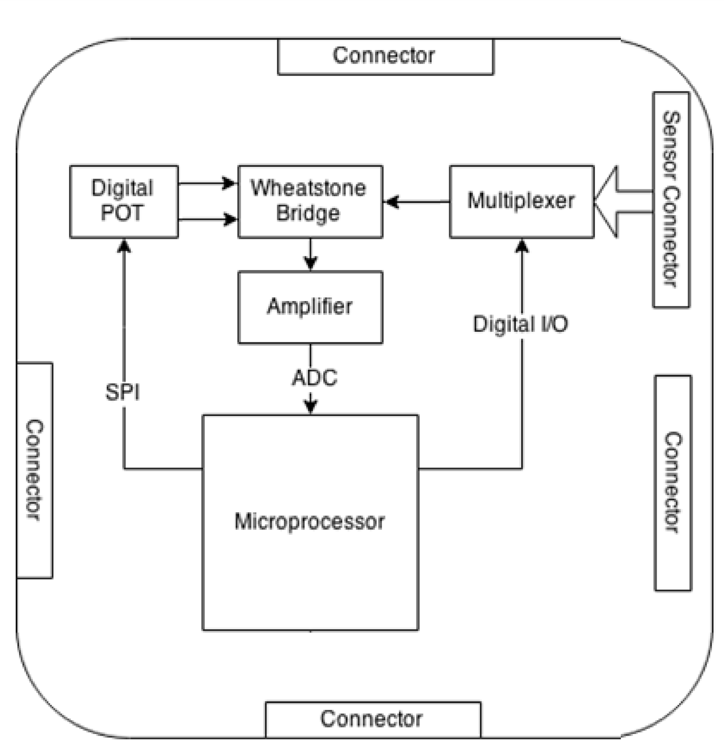




$$R = R_1 + (R_2 - R_1)\left(\frac{p - p_1}{p_2 - p_1}\right) + (R_3 - \hat{R})\left(\frac{q - q_1}{q_3 - q_1}\right)$$

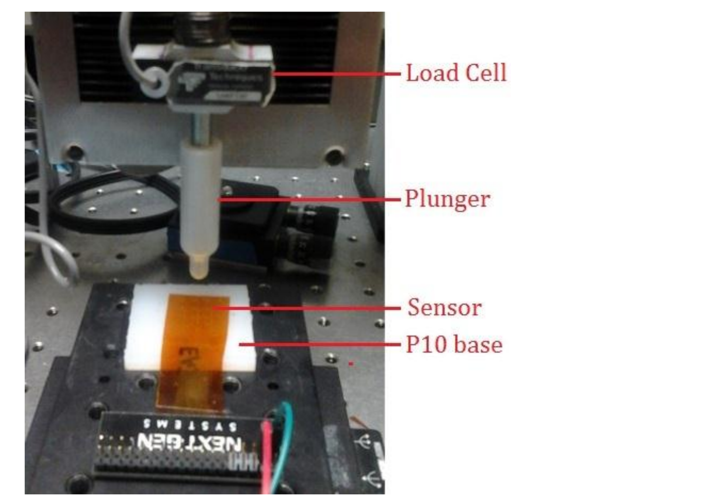
$$\hat{R} = R_1 + (R_2 - R_1)\left(\frac{p_3 - p_1}{p_2 - p_1}\right)$$

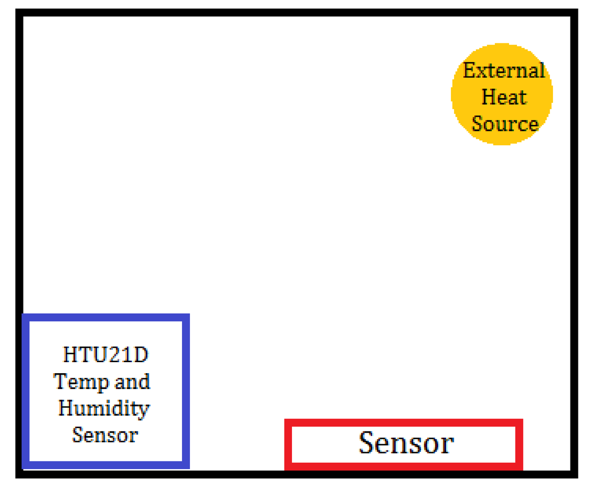
SkinCell: Sensor interfacing module



An analog multiplexer, CD74HC4067, was used to switch between 16 sensors to connect with Wheatstone bridge one at a time. A digital potentiometer, AD5174, was used to balance out the bridge. An instrumentational amplifier, AD623, was used to amplify the differential signal. A microcontroller, ATmega2560, was used for ADC and data preprocessing.

Pressure and Temperature Testing

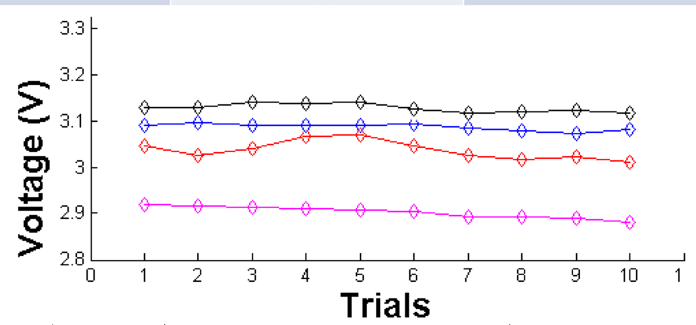




To evaluate performance, sensor arrays were loaded in controlled conditions with pressure ranges 0-10 psi, and exposed to temperature and humidity cycles.

Test No.	Room temp. resistance (Ω)	Temp. Sensitivity (mV/⁰C)	Avg. Sensitivity (mV/⁰C)	Humidity Sensitivity (mV/%RH)	Avg. Sensitivity (mV/%RH)
1	345	190	175	8.54	7.88
2	212	170		7.89	
3	250	176		7.56	
4	301	150		8.02	
5	313	180		8.12	
6	225	175		7.6	
7	311	183		8.3	
8	330	181		8.4	
9	280	176		7.68	
10	202	140		6.89	
11	323	191		7.8	
12	295	182		7.81	

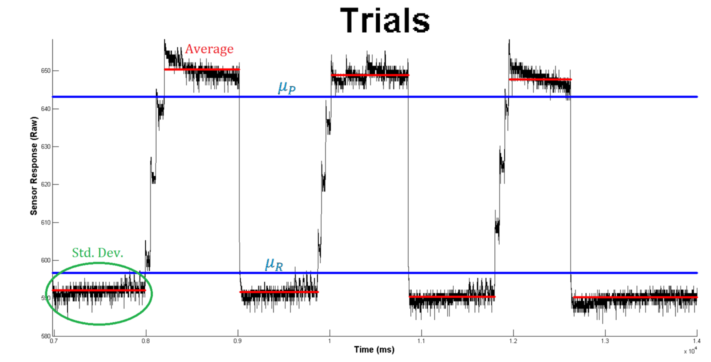
Taxel #	Avg. Pressure (lb)	Avg. Output (V)	Std. Dev. (mV)
1	1.062	3.086	7.1
6	1.043	3.037	20.7
11	1.057	3.127	12.9
16	1.049	2.902	9.0



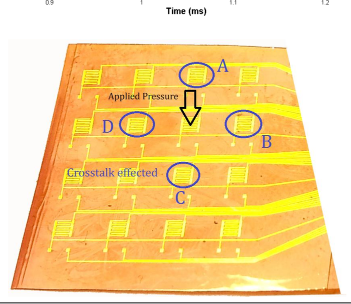
$$SNR = \frac{\mu_P - \mu_R}{\sigma}$$

μ_P = Mean value when pressure is applied
μ_R = Mean value in resting position
σ = Standard deviation of the signal

Taxel #	Std. Dev. (V)	SNR
1	1.7844	13.07
6	2.6144	17.01
11	2.02	16.92
16	2.1376	20.6



Center Sensor reading (V)	Crosstalk reading (V)				Average(V)	Percentage
	A	B	C	D		
3.13	2.92	2.92	2.93	2.93	2.924	6.76%
3.1	2.89	2.89	2.901	2.91	2.899	6.58%
3.03	2.9	2.87	2.902	2.904	2.9	4.2%



Conclusions and Future Work

We presented fabrication, packaging, electronic interconnection and testing of SkinCell, a 4x4 EHD printed pressure sensitive array. The advantage of our approach is in its flexibility in terms of substrate topography, ink formulation, and sensor pitches. Results of sensor printing with PEDOT:PSS mixed with DMSO (1:3) show good crosstalk, SNR, repeatable results across the array, and low sensitivity to humidity. The measured pressure resolution was approximately 0.15 psi for a range of 10psi, and a bandwidth of at least 10 Hz, making them excellent choices for physical human-robot interaction applications. Results also show high temperature sensitivity, and future work includes: temperature compensation, more testing of inks/geometries/loading conditions, larger surfaces skin arrays, application on robot limbs and integration with robot controllers.

Acknowledgement and References

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[4] Mirza, F., et. al., "Piezoresistive Pressure Sensor Array for Robotic Skin," *Proc. of SPIE* DCS, Baltimore, MD, April 2016
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