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Supplementary Materials for

Bend, stretch, and touch: Locating a finger on an actively deformed transparent sensor array

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The PDF file includes:

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- fig. S4. Steps of mechanical test.
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- Reference (*38*)

Other Supplementary Material for this manuscript includes the following:
(available at advances.sciencemag.org/cgi/content/full/3/3/e1602200/DC1)

- movie S1 (.mp4 format). Video showing proximity detection.
- movie S2 (.mp4 format). Video showing the sensor being stretched and then being touched while being stretched.
- movie S3 (.mp4 format). Video showing the sensor being bent and a finger touching it while bending.
- movie S4 (.mp4 format). Video showing a finger moving across the sensor and the sensor’s response to it.
- movie S5 (.mp4 format). Video showing multiple fingers touching the sensor at multiple locations.

- movie S6 (.mp4 format). Video showing an accidental coffee spill on the sensor and continued functionality after wiping it clean.
- movie S7 (.mp4 format). Video showing a wrist gear made using this sensor and an LED grid under it to demonstrate potential use as part of a wearable device.

Effect of Scaling on Sensor

We seek to understand how sensor size will affect resolution. Our analysis suggests that the sensor can be scaled down to increase resolution without change in sensitivity due to the linear relationship between capacitance and the scaling factor. This scaling relationship is clear for a parallel plate capacitor in which the capacitive, $C = \epsilon \frac{A}{d}$, (A = area of the electrode, d = distance between electrodes) where scaling the size equally of all dimensions of the capacitor results in increasing the capacitance by second order due to the increase in area and a decrease by first order due to the increase in dielectric thickness. Overall this gives rise to a linear increase in capacitance with scaling. The same scaling law applies to other capacitor geometries also, as we now argue. This in turn also means that the relative change in capacitance due to a scaled 'finger' is also constant with scaling.

The argument is made using the case of two co-planar electrodes acting as mutual capacitance sensors, as depicted in fig. S1.

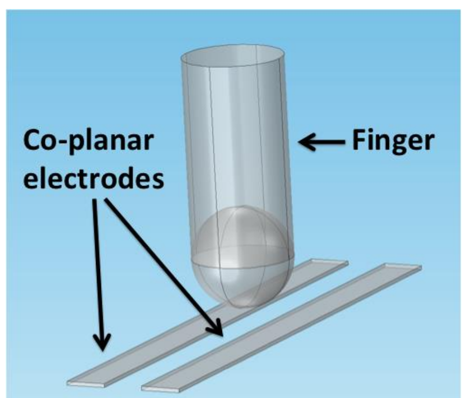

fig. S1. Coplanar electrode capacitor with a finger.

In this case the capacitance is analytically calculated using conformal mapping for the coupling between the top surface of the electrodes and using parallel plate approximation for the edges of the electrodes facing each other. The conformal mapping approximation of co-planar plate capacitance *(38)* is given by

$$Ccm = \varepsilon \times l \frac{K(k')}{K(k)}$$

(where, l = length of the electrodes, K() is the complete elliptic integral of first kind, $k = \frac{d}{2w+d}$, and $k' = \sqrt{1-k^2}$). The results show a linear increase in capacitance with scaling factor.

A COMSOL finite element simulation tool is used to verify the results and the model shown in fig. S1 gives a similar linear increase in capacitance with scaling factor as with the conformal mapping model.

Now having established the fact that the capacitance will scale with scaling factor we investigate the effect of scaling on sensitivity in an array implementation as shown in fig. S2.

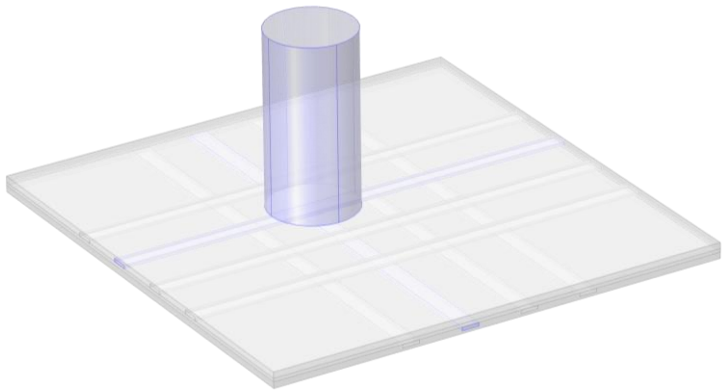

fig. S2. Finger on an array of capacitive sensors.

A finger touches the taxel (2,2). The simulation is initiated with the width of the electrodes as 2 mm and spacing between them as 5 mm (edge to edge) and thickness as 0.4 mm (set 1). This gives rise to a change in capacitance of 18% at the taxel being touched while the adjacent taxels experience a change in capacitance of 8% providing sharp localization of the finger. The system is then scaled down by 10 times (set 3), which effectively made the electrodes thinner and brought the taxels closer together. The changes in capacitance for the taxels along the 2nd row are plotted in fig. S3. It is observed that the relative change in capacitance (dC/C) for a 0.4 mm thick electrode with a finger diameter of 10 mm is exactly the same for the 0.04 mm thick electrode case with a finger diameter 1 mm (can be the tip of a stylus).

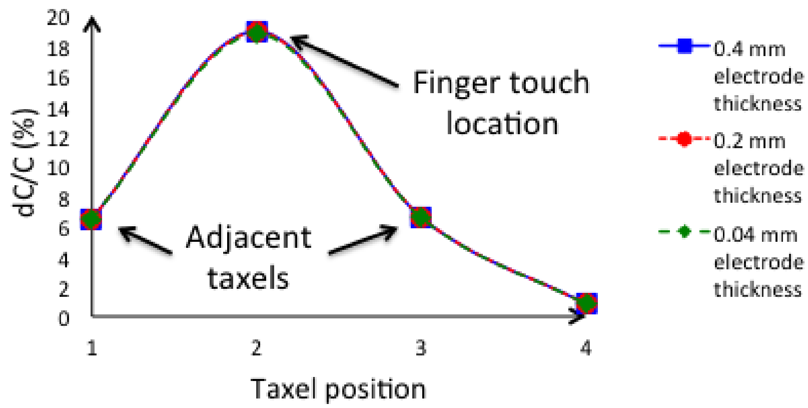

fig. S3. Effect of scaling on change in capacitance along a row due to a touch at a single taxel.

The scaling of the sensor array therefore has no effect on the functionality of the sensor. The smaller the electrodes, the finer the lateral resolution. However it does cause the lateral and vertical resolution to change with the scaling factor. The scaling of resolution is the same in the vertical direction.

Mechanical Characterization: Cyclic Loading

In this section we provide details on the cyclic mechanical characterization test conducted on the sensor. The test is conducted to demonstrate the mechanical robustness of the sensor in response to repeated stretching and bending.

The sensor is clamped at two edges leaving 20 mm of active area between the clamped edges. Under this condition, the sensor was stretched by 2 mm to induce a strain of 10%. Following this stretch, the sensor is then buckled by 3 mm inwards to provide a bending with a radius of curvature of 16 mm. The stress is applied using a Bose Electroforce dynamic mechanical analyzer.

The steps of the experiment are shown in fig. S4 below.

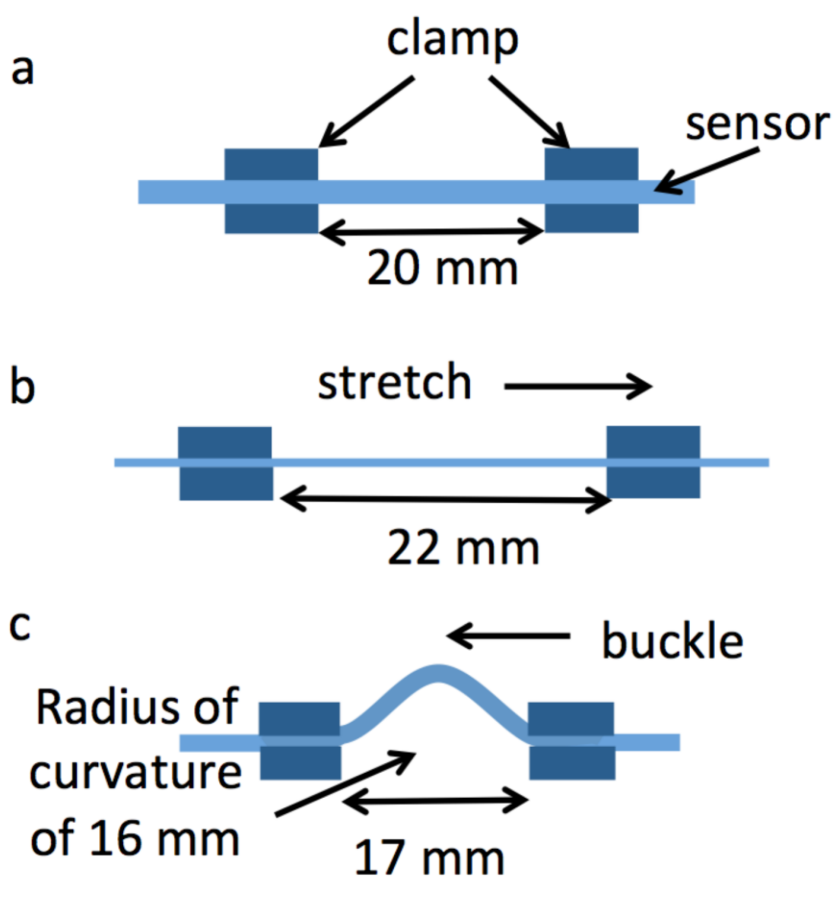

fig. S4. Steps of mechanical test. (**a**) Steady state (**b**) stretched by 10% strain (**c**) buckled with an approximate radius of curvature 16 mm.

The radius of curvature is calculated using image processing in Matlab. The strain at the surface of the buckled sensor is ±6% (calculated using $\epsilon = \frac{a}{\rho}$, where a is the distance from the neutral axis of the sensor to the top/bottom surface = 0.9 mm and ρ is the radius of curvature = 16 mm).

This cycle is repeated 500,000 times at a frequency of 1 Hz in a water bath. The bath ensures that any changes seen are not due to evaporation of water from the gel. The sensor is unclamped and tested for finger touch sensitivity during the cycling at the point of maximum bending. No significant drop in performance is observed over the test, and there is no visible damage to the sensor array, as evident from the plot in fig. S5.

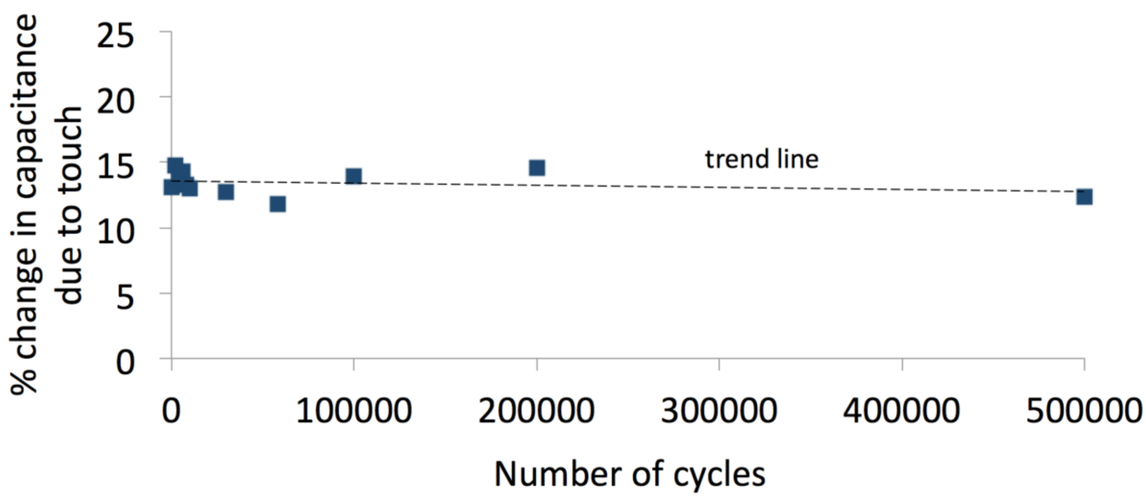

fig. S5. Plot showing change in capacitance in percentage due to a touch after cycles of 10% strain, followed by a buckling with a radius of curvature of 16 mm.