

Fast Tactile Sensor Array Normalization of an Artificial Silicone Fingertip Using a Pressure Chamber

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Summary: We present an approach for normalizing the output of tactile sensor arrays to reduce taxel-to-taxel variations due to manufacturing. The method is applied to a soft, artificial fingertip containing 144 integrated capacitive taxels. A pressure chamber applies uniform forces, to all taxels, simultaneously. Two normalization methods are proposed and compared: one based on the maximum taxel capacitance change and another based on a fitted sigmoid function. Both methods reduce taxel spread (coeff. of variation from 0.41 down to 0.23 and 0.085 respectively), improving tactile image uniformity.

Keywords: Normalization/calibration, tactile sensor array, pressure chamber, sensor linearization.

Background

Soft artificial fingertips with high spatial resolution are expected to significantly advance dexterous robotic manipulation [3]. Fluctuations during fabrication of these complex devices result in taxel-to-taxel variations. This makes rapid and consistent taxel normalization a critical requirement for practical use in robotic grasping and manipulation. To overcome the limitations of sequential single-taxel characterization, which is slow for high-density arrays, a pressure chamber is introduced to enable simultaneous, spatially uniform loading of all taxels. While pressure chamber-based approaches have been explored in prior work, they often rely on deformable membranes [1] or bladder interfaces [2].

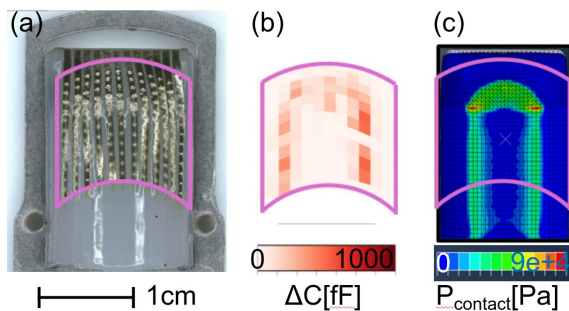


Fig. 1. Technology overview: (a) artificial fingertip with embedded tactile sensing array containing 12x12 tactile sensing units. Sensing area is indicated by pink shape. (b) Tactile image under loading of flat indenter showing ΔC for each taxel. (c) FEM simulation of same load case as in (b) showing contact pressure.

Description of new Method

Since each capacitive taxel features an air gap fully encapsulated in silicone [3], the fingertip can be characterized using a simple pressure

chamber. This avoids using a bladder or membrane that may introduce load inhomogeneities.

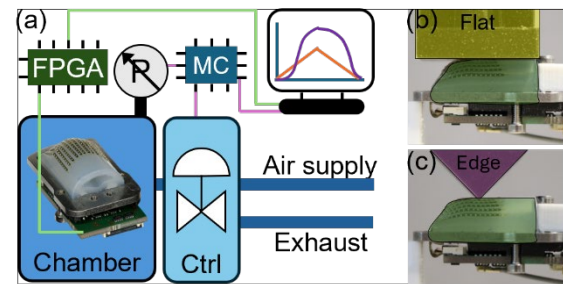


Fig. 2. Experimental setup: (a) schematic representation of setup including pressure chamber, pressure controller (Ctrl), pressure sensor (P), Arduino (MC) and Field Programmable Gate Array (FPGA) to read out artificial fingertip taxel response. (b) Real world load cases where the artificial fingertip is indented with a flat or (c) edged indenter.

Two taxel array normalization approaches were developed. In the *Maximum Capacitance* normalization (**Max**), the recorded change in capacitance (ΔC) of each taxel is divided by its maximum response at peak pressure (ΔC_{Pmax}), as defined in Eq. (1). The expected taxel outputs are in the range of 0 to 1 and unitless.

$$\Delta C_{norm} = \frac{\Delta C}{\Delta C_{Pmax}} = \frac{\Delta C}{\Delta C(P=3000mbar)} \quad (1)$$

In the *Inverse Sigmoid Normalization* (**Sig**), the parameters L, k, P_0, α describing a sigmoid function with linear extension, as defined in Eq. (2), were found for each taxel using least squares fitting. Thereafter, Brent's root finding method was applied to predict the input pressure in mbar ($P_{\sim}$) from a measured ΔC .

$$\Delta C(P) = \frac{L}{1 + \exp(-k(P - P_0))} + \alpha \cdot P \quad (2)$$

Results and Discussion

Raw sensor responses measured in the pressure chamber exhibit a characteristic “S”-shaped behavior in the ΔC -P curves (Fig. 3a). Taxel variations (average coefficient of variation CV: 0.41) arise from variations in cover layer thickness, taxel orientation, initial membrane gap, and parasitic capacitances. Normalization using **Max** partially compensates for these effects (Fig. 3b, average CV: 0.23), yielding outputs scaled between 0 and 1. However, the response remains strongly nonlinear, with significant variability particularly in the mid-pressure range. While this approach is simple and robust, it does not fully correct taxel-to-taxel variations. In contrast, applying the **Sig** normalization and estimating the pressure at the taxel level results in a substantially more linear response and improved performance across the full pressure range (average CV: 0.085), as shown in Fig. 3c.

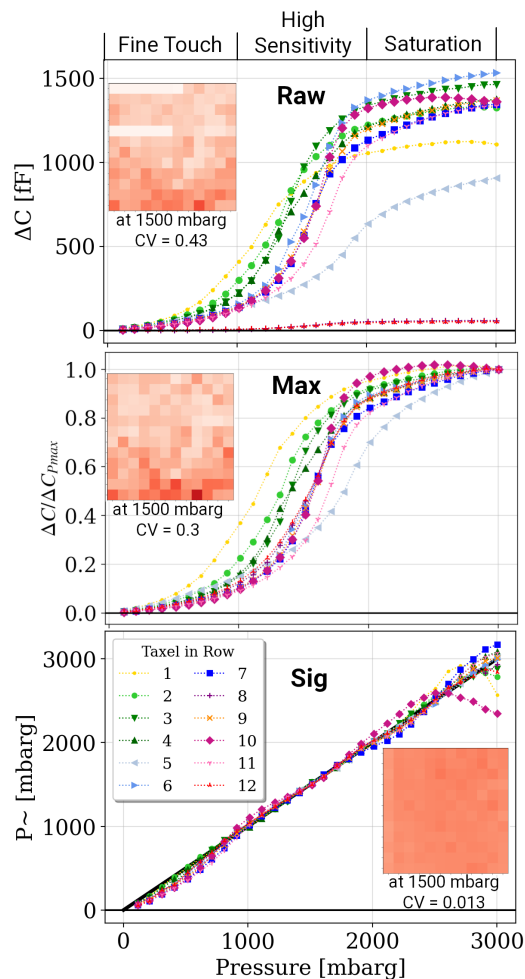


Fig. 3. Uniform pressure loading: (a) Response of 12 taxels showing output variations. (b) Using the **Max** normalization, the taxel outputs are normalized between 0 and 1. (c) Using the **Sig** normalization for each taxel response leads to linearization of the output. (Insets) full 12x12 tactile images with CV values.

The effect of normalization on real finger indentation scenarios is shown in Fig 4 for a flat and an edge rigid indenter. The **Max** normalization resolved the large variation in output intensity and compensated low sensitivity regions, bringing the images closer to simulated contact pressure fields. For the sigmoid fit, this effect was even more pronounced, but also some smearing out was observed due to high sensitivity to non-ideal fitting parameters at very low ΔC and P values. Future work will evaluate the effect of the different normalization procedures on the performance of robotic in-hand object manipulation.

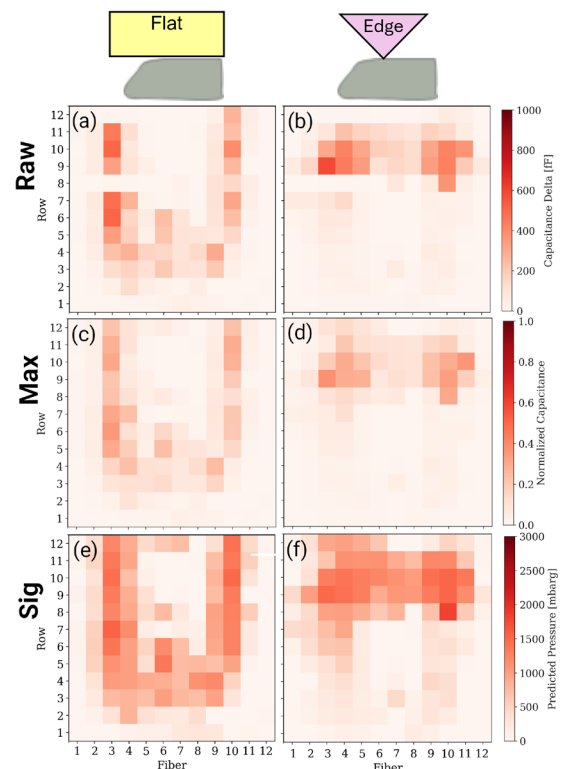


Fig. 4. Rigid indenter load cases: Raw capacitance data when pressing on a flat surface (a) and swiping over edge (b). Using **Max** normalization increased the response of weak taxels, resulting in a more uniform tactile image (c, d). Using **Sig** normalization, the predicted taxel pressure is further homogenized but also smeared (e, f).

References

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