Electronic Supplementary Material (ESI) for Lab on a Chip

Electronic Supplementary Information

Iontronic Microdroplet Array for Flexible Ultrasensitive Tactile Sensing

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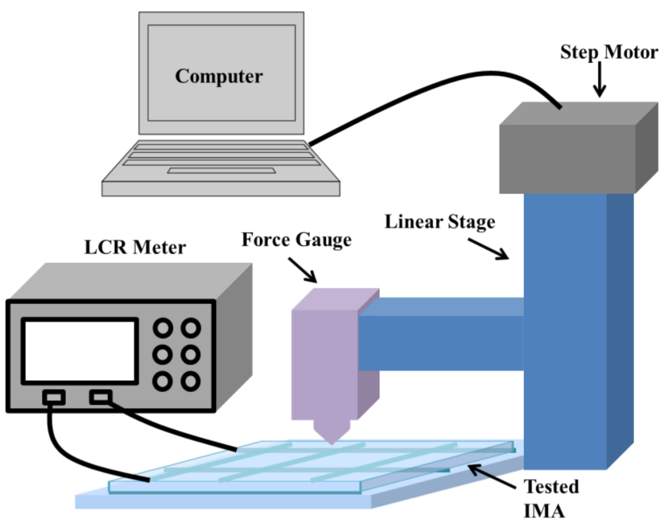
Measurement Setup

The measurement setup is comprised of a high-precision force gauge amounted on a computer-controlled step motor. Mechanical loads (as point forces) can be precisely applied to the surface of any single sensing unit, and the corresponding displacements can be controlled and monitored simultaneously. The pressure values are calculated as the ratio of the applied forces to the surface area of the membrane in a single sensing unit. The corresponding capacitive changes are directly recorded through a LCR meter.



Supporting Figure S1. Schematic illustration of the experimental setup for the device sensitivity calibration.

Mathematical Derivations for the Mechanical-to-Capacitive Sensitivity

Mechanical Deformation

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The deformations of the flexible sensing membranes will lead to the change of the droplet-electrode contact area, and therefore, result in the variations of the capacitive values. More specifically, small deflections of the membranes can be mathematically predicted according to the classic thin-plate theory. The relationship between the membrane deflection (y) and external force (ΔF) can be expressed as:

$$y = \frac{(1-v^2)a^2}{5ET^3}\Delta F \qquad \text{(S1)}$$

where v, E and T represent Poisson ratio, Young's modulus and thickness of the sensing membrane, respectively. a is the spatial resolution or pinch-to-pinch distance of an iontronic microdroplet array (IMA) device.

Deformation-Induced Capacitive Change

The membrane deflections will result in deformations of the ionic liquid (IL) microdroplets. Therefore, the area of liquid-solid contact interface (ΔA) is caused to change, which will lead to a variation in the interfacial capacitance (ΔC).

$$\Delta C = c_0 \times \Delta A = c_0\left(\frac{V}{h-y} - \frac{V}{h}\right) = C_0 \times \frac{y}{h-y} \approx C_0 \times \left[\frac{y}{h} + \left(\frac{y}{h}\right)^2\right] \qquad \text{(S2)}$$

where c_0 and C_0 are the unit-area capacitance and initial electric double layer capacitance respectively. V indicates the volume of the sensing droplet and h is the initial height of the sensing chamber.

Mechanical-to-Capacitive Sensitivity

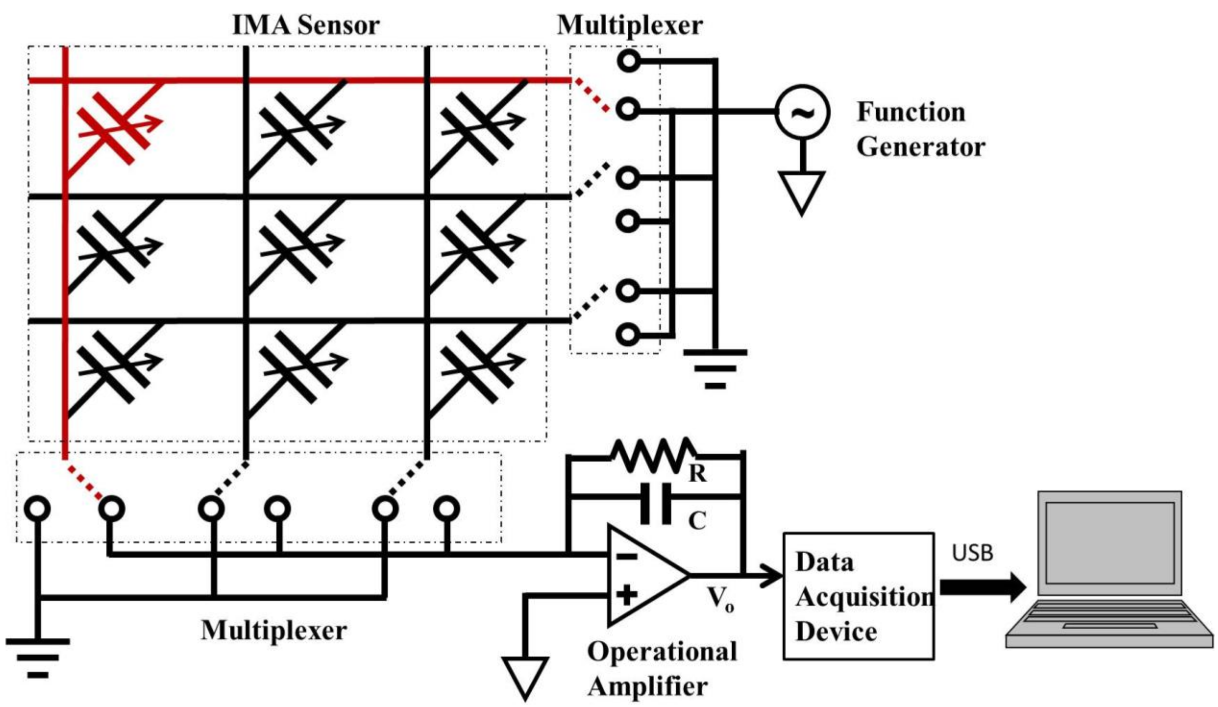
Combining Eqs. S1 and S2, the governing equation can be derived for the overall mechanical-to-capacitive sensitivity of the IMA sensors as follow, where K represents a structurally dependent constant:

$$\Delta C = C_0 \times \frac{\Delta P}{K - \Delta P} \approx C_0 \times \left[\frac{\Delta P}{K} + \left(\frac{\Delta P}{K}\right)^2\right] \quad \text{(S3)}$$

$$K = \frac{5ET^3h}{(1-\upsilon^2)a^4} \quad \text{(S4)}$$

Circuitry for IMA electrical signal measurements

A measurement circuitry has been built to assess the electrical readouts from the IMA devices. The circuit consists of a pixel selection unit, a signal amplification unit, and a data acquisition unit (Figure S2). All of the individual pixels can be addressed by two orthogonally controlled multiplexers (CD4053BE, TEXAS INSTRUMENTS), which are regulated by a microcontroller (M430, TEXAS INSTRUMENTS). Once a pixel is selected, the output signal (V_0) goes through an operational amplifier (LM358AN, STMicroelectronics) and is measured by a 16-bit data acquisition module (NI USB-6210, NATIONAL INSTRUMENTS). The data acquisition algorithms are programmed in LabVIEW (National Instruments), and the recorded data are processed in MATLAB (MathWorks).



Supporting Figure S2. Data acquistion circuitry for the IMA devices. The sensing units were addressed by two multiplexers, and the corresponding outputs were amplified though an operational amplifier and recorded by a data acquisition board.