Flexible Piezoelectric Pressure Sensors with In-Memory Computing Capabilities for Intelligent Electronic Skin

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In the Internet of Things (IoT) era, billions of connected sensors communicate data with cloud computing platforms continuously. In the currently deployed smart sensor systems, sensing and computing occur in separate physical locations, imposing a vast amount of data shuttling between the sensor module and the cloud computing platforms. This data movement has a negative impact on the environment, the latency, and capacity for processing sensor data. Therefore, it is of utmost importance to build intelligent sensing systems where arrays of sensors are integrated with memory and computing functionalities so that sensory data can be preprocessed at the sensor node. Here, we report arrays of polymeric ferroelectric sensors, capable of sensing static and dynamic touch and their integration with memristor crossbar array-based in-memory computing hardware for the classification of touch, similar to human skin. These near-sensor computing platforms will be capable of computing at the extreme edge so that only the essential data will be sent to the cloud for further processing, substantially reducing data communication and increasing computing efficiency.

In this work, we demonstrate the feasibility of fabricating ferroelectric e-skins, using the versatility of ferroelectric physics and the mechanical flexibility of the ferroelectric polymers, that can successfully detect low-frequency static signals and high-frequency dynamic signals. A piezoresistive sensor array is normally used to detect various static mechanical stimuli, including normal, shear, stretching, and bending forces while a piezoelectric sensor array is used to detect the dynamic changes in pressure, acoustic vibrations etc. In the current work, we integrated both the functionalities in the sensor array to demonstrate skin-like capability of both static and dynamic touch sensing. The easy fabrication technique of the sensors (as can be seen from the device schematics in Figure 1) and scalability of the process ensure possible large-volume production of such e-skins. Figure 2 shows the sensor output voltages in response to multiple touch and release operations. The sensor output voltage depends critically on the magnitude of applied pressure how quickly the pressure is applied and released. These sensor arrays are then integrated with a functional circuit to preprocess the signal and make it suitable for working as input to a memristor crossbar array based in-memory computing circuit. The preprocessing circuit function diagram is shown in Figure 3. When scaled successfully, these integrated computing sensors might find applications in robotic skins, wearable self-powered pressure sensors, and medical diagnostic devices for vital health signal monitoring.

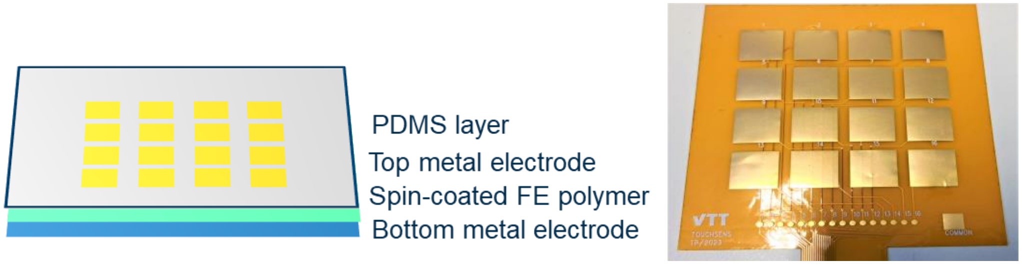

Figure 1: The device schematics of the Ferroelectric touch sensor (Left) and the Image of the 4x4 sensor pixels on flexible substrates (Right).

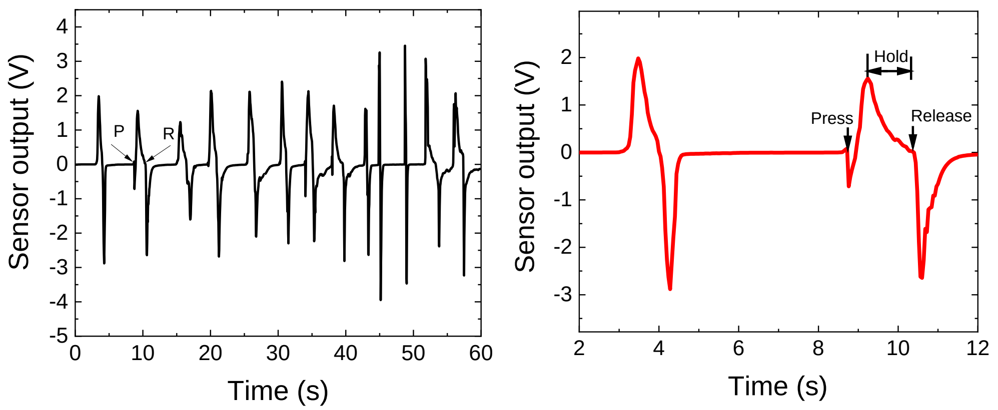

Figure 2: The Ferroelectric touch sensor's response to static and dynamic pressure. Left: The sensor output in response to multiple touch and release operations. The arrow shows when the pressure was applied, a positive peak voltage was generated, while the release of pressure resulted in a negative voltage spike. How quickly the press and release were made determines the output voltage magnitude, while during the hold time, the sensors show an exponential decay of the output voltage. Right: Magnification of the operations, leading to the static and dynamic effects of the sensors.

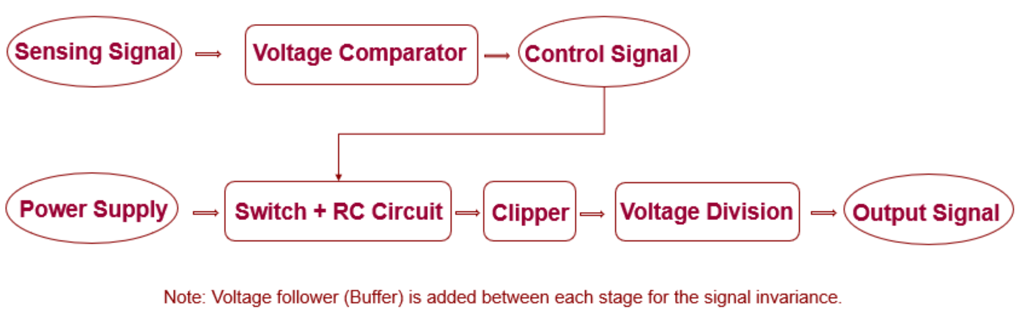

Figure 3. Signal Preprocessing Circuit (Connection Circuit) Function Diagram.