NEWS AND VIEWS

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# Healthcare electronic skin devices

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Electronic skin (e-skin), a kind of flexible sensor arrays and system that mimic the properties and sensing functions of human skin, represents a new paradigm of sensing and control (Fig. 1). The noun of "skin electronics" made its debut in the Sensitive Skin Workshop organized jointly by the National Science Foundation and Defense Advanced Research Projects Agency of USA in October 1999 in Arlington, VA. The experts attending the workshop proposed the concept of "sensitive skin-like devices", which are the flexible electronic device and system covering the surface of machine or human body, and confer the carrier with sensing capabilities of the tactile, pressure, temperature, chemical, or biological information.

In the past decades, the improvement of people's living standards has been benefited from technological progress and economic development, however, people's quality of life will mainly depend on their health in the future. By endowing wearability to electronics, electronic skin devices have shown significant potential for healthcare applications including health-monitoring devices and biomimetic prosthetics. In recent years, electronic skin devices have received rapid development from the aspects of principles, methodology, and prototypes to meet the huge demand of commercial electronics, for example, the globe wearable device market reached about US$ 20.6 billion in 2018. It can be envisioned that the lack of sensitive electronic skin is the bottleneck of healthcare applications in internet of things (IoT).

The challenging aspects toward the advancement of electronic skin devices include the development of novel materials with skin-like properties, sensor units with breakthrough in principles and performances of key parameters, and multiplex functions and system integration.

i) Skin-like Properties. To mimic natural human skin, the choice of materials is a crucial aspect of e-skin devices aimed for healthcare. Materials with modulus similar to epidermis are expected to achieve mechanical flexibility and stretchability, and enable conformal contact between devices and dynamic structured human skins or complex machine surfaces. Bao *et al.* reported an intrinsically stretchable transistor array and realized combination of advanced electronic functionality with skin-like stretchability, which allows for data reading for high density flexible pressure sensor arrays[1]. To maintain functional properties under high strains, Someya *et al.* reported a composite nanofiber-based bending-insensitive and ultraflexible pressure sensor, which measures only the normal pressure, even under extreme bending conditions[2].

ii) Novel Sensing and Processing Technologies. Inspired by cutaneous receptors in human skins, novel sensing and processing technologies are explored efficiently processes complex tactile information.

The development of electronic skin device provided potential to supplant the sensing ability of limb prosthetics or replace damaged human skin. The biggest challenge is the translating between analog and digital signals. Bao *et al.* used a ring oscillator circuit to translate the analog signal of pressure sensor into the series of voltage spikes similar to that of the mechanoreceptors of human skin, and successfully converted pressure information into a spike voltage digital response[3]. Furthermore, they developed neuromorphic tactile sensory system based on flexible organic electronic circuits that can encode tactile stimuli to digital pulses (spikes or action potentials) and eventually actuate the movement of acockroach leg[4]. These works paved the way to prosthetics withsensing and actuating functions.

iii) Parameter Improvement. Key parameters (e.g., sensitivity, hysteresis, working range, linearity, and stability) are critical for improvement of sensors for specific application scenario. Efforts have been made to enhance sensing capabilities based on material engineering, device designs, and novel manufacturing methods.

Typically, sensitivity of pressure sensors is improved by utilizing soft materials and microstructures with lower modulus. Cheng *et al.* achieved sensing performances of low hysteresis and short response time to enable high-precision and high-speed detection utilizing silicon nanowires[5].

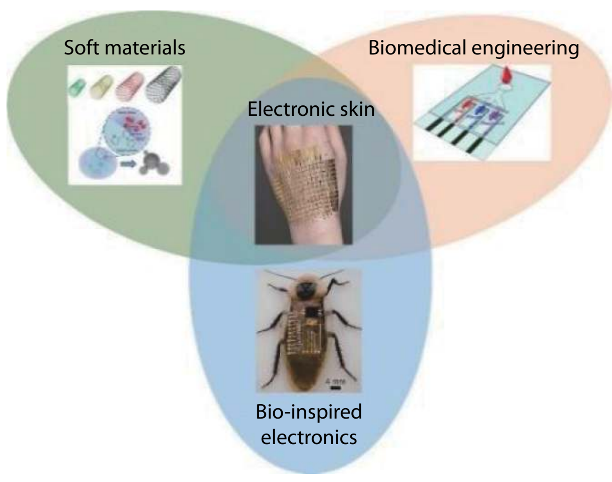


Fig. 1. (Color online) Electronic skin involves multi-discipline of soft materials, biomedical engineering, and bio-inspired electronics.

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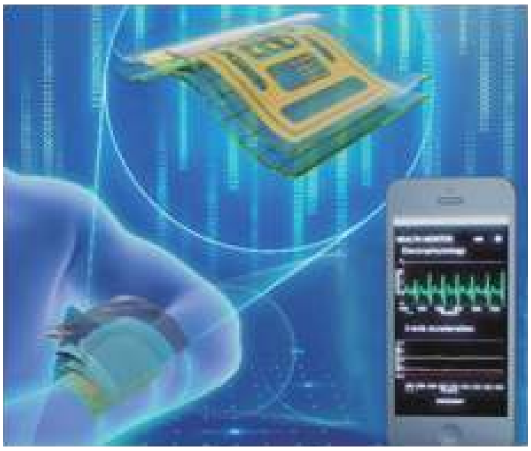

Fig. 2. (Color online) Schematic illustration of a wearable electronic skin devices.

iv) Multiplex Sensor and System Integration. Simultaneous and selective monitoring of various physiological signals are of great necessity in developing smart and interactive healthcare applications. Many multifunctional sensory systems were designed to be able to measure on real-time with pressure, strain, temperature, humidity, electrophysiology, or biochemical information from either physical vibration/motion or body fluids like sweat. However, the complexity of device fabrication and integration, decoupling of signal analysis, and multiple-signal interference are the problems to be solved.

v) Intelligent Functions. In addition to basic sensing capabilities, e-skin with more intelligent functions and features are highly demanded to expand their practical applications. Wireless data transmission can avoid complicated equipment and technologies like near field communication endow e-skin with portable and smartphone-communicable features (Fig. 2). As an example, Bao *et al.* designed a wireless arterial-pulse pressure sensor based on inductive coupling[6]. Other important functions including self-healing, self-power, self-cleaning, and dynamic drug delivery are also expected in the field of healthcare applications.

In summary, e-skin has gained much interest as a promising platform for advanced healthcare applications with excellent skin-like properties and sensory functions. Despite the great advances in e-skin, several challenges should be further addressed in the future like novel responsive materials and structures, system-level integration, low-cost large-scale fabrication, and system-level integration of multifunctional sensors.

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