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Biofuel-powered electronic skin: future of healthcare

Electronic skin (e-skin) is a technological advancement over the human skin that can provide sensory facilities against temperature, and pressure measured along with extra mechanical durability and stretchability[1]. Augmentation on e-skin can be done by incorporating near- or medium-range wireless communication with the help of integrated microcontroller assembly. Such e-skins are useful in smart healthcare applications[2].

A person wearing an e-skin assembly can transmit vital information about his/her health to a remote system for immediate medical intervention. Bluetooth and Wi-Fi modules could be equipped with the e-skins to facilitate ultra-flexible smart healthcare services in the near future[3]. Existing e-skins are usually powered by near-field communication tags or in-built miniature batteries that may sometimes hinder continuous data transmission[4]. Upon discharge of the battery, e-skins tend to stop regular activities[5].

A recent study has demonstrated the efficiency and applicability of biofuel-powered e-skin development for better healthcare[6]. The e-skin is completely self-powered by human fluids (human sweat). Thus, a fully perspiration-powered integrated e-skin (PPES) has been devised to harness energy from lactate biofuel cell to act as a biomarker of essential human excretions like urea, NH_4^+, glucose and pH.

PPES uses a pair of bioanodes and biocathodes to sense human vitals. It can work in continuous 20 mM lactate medium over human skin and regularly send vital information from an array of

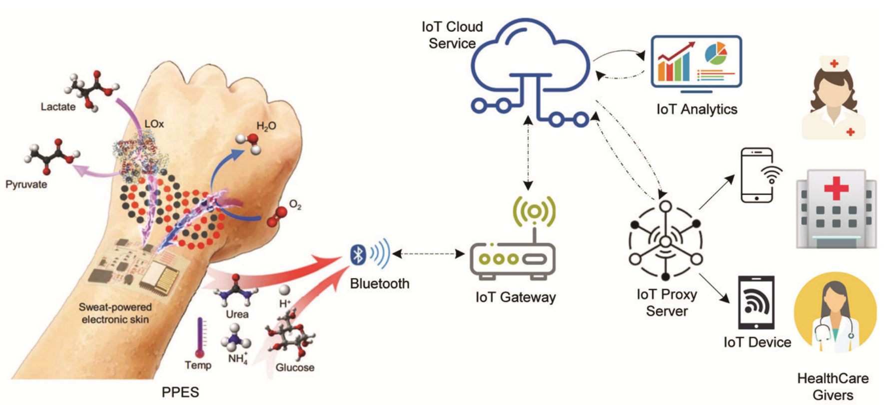

Figure 1. Perspiration-powered integrated e-skin (PPES) enabled with internet of things infrastructure from smart healthcare (PPES image courtesy Yu *et al.*[6], modified by authors).

biosensors. The PPES runs at 3.3.V with minimum 100 μA current. The power consumption during deep-sleep is about 9.35 mA at 10 ms sleep cycle. The system can work with 400 μF capacitor for a continuous 60 h of steady operation. Figure 1 presents the design and fabrication aspects of PPES.

Strain sensor can also be used with PPES to monitor real-time wireless human machine interaction. The prototype is built from sandwich structure of M-tape-polydimethylsiloxane (PDMS)–M-tape encapsulation. The bioanode is made from h-Ni microstructures with rescued rGO films and Meldola's blue-tetrathiafulvalene carbon nanotube. It uses a booster module from Texas Instruments (BQ25504) to harvesting energy from human sweat. Also, a test is performed to check compliance with human protocol.

This research presents a new dimension of augmented biomedical notion with a collective support from the advanced materials design, bio-signalling and improved information communication technology enabled futuristic vision. We add that PPES may also be tested in conjunction with the emerging internet of things platforms[7] to make it more suitable to cater to smart healthcare in coming days.

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