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A Hybrid Piezoelectric - Electrostatic Energy Harvester for Wearable Biosensors

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Summary:

Biosensors play a crucial role in modern healthcare, providing continuous monitoring of various physiological parameters. However, the reliance on batteries that require replacement introduces interruptions in data acquisition process and for this reason energy harvesting methods that convert human body energy into electricity have attracted considerable research interest. In this study, a novel hybrid energy harvester that combines piezoelectric and reverse electrowetting on dielectric (REWOD) techniques is investigated. The key working principle revolved around the electrical double layer present in the REWOD component and coupling it with a piezoelectric generator via an electret. By harnessing biomechanical vibrations with a piezoelectric material and the REWOD unit, the overall power output of the biosensor was enhanced. The proposed design was evaluated through numerical simulations and a series of experimental tests. The findings contribute to the advancement of self-powered biosensors, enabling seamless and continuous data acquisition without relying on external batteries.

Keywords: energy harvesting, REWOD, piezoelectric, electrical double layer, wearable biosensors, continuous monitoring

Title

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Headlines

This work discusses the development of a novel hybrid energy harvester that combines piezoelectric and reverse electrowetting on dielectric (REWOD) technologies.

Background, Motivation an Objective

Modern healthcare relies extensively on implantable and wearable biosensors to continuously monitor physiological data of patients. These devices can play a crucial role among others in disease prevention, treatment of injuries and facilitating recovery [1]. However, a significant drawback of biosensors lies in their reliance on batteries for power supply and batteries present in biosensors pose challenges such as miniaturization, potential electrolyte leakage, and costly replacement surgeries for implantable devices [2]. For instance, wearable glucose biosensors require the battery to be periodically changed, which introduces discontinuity in data acquisition and discomfort due to skin penetration.

These limitations can be addressed by development of energy harvesting devices. The human body has multiple energy sources that can be effectively harnessed by various transducers [3]. These sources include thermal energy, biochemical reactions, electrostatic charges, and biomechanical forces. However, relying solely on a single energy type may not yield optimal power output or guarantee that the energy is constantly available. Therefore, hybrid energy harvesters combine multiple energy generators to enhance overall performance.

This study investigates biomechanical energy produced by the human cardiovascular system. More specifically, pulsations from the radial artery serve as a reliable source of vibrations that can be scavenged. The proposed hybrid energy harvester combines piezoelectric and electrostatic generators to extract energy from a time-varying radial artery pressure.

Description of the energy harvester

Recent advancements in electrowetting have introduced a novel effect known as the reverse electrowetting on dielectric (REWOD). In a typical REWOD setup, a conductive liquid droplet is squeezed between two electrodes, one of which is coated with a dielectric material [4]. By modulating the distance between these electrodes, the electrical double layer (EDL), which formed at the fluid-electrode interface, can be altered [5]. The formed variable capacitor can be used for charge accumulation.

The working principle of the designed energy harvester is described in Table 1 and Figure 1:

Tab. 1: Hybrid harvester states

State	Description
Initial State	The piezoelectric material and REWOD component are in equilibrium, with no electron flow.
External Pressure	When pressure is applied to the piezoelectric material, sustained deformation causes an electron flow between the electrodes. One of the electrodes becomes positively charged.
Electret Biasing	The shared electrode features an electret layer which biases the REWOD component. This prevents ions and counter ions in the EDL from changing positions. The EDL, which is formed on top of the electret, increases the overall capacitance of the system, maximizing charge generation.
Release of Pressure	As pressure is released and the harvester returns to its initial state, the process repeats, with electrons flowing in the opposite direction.

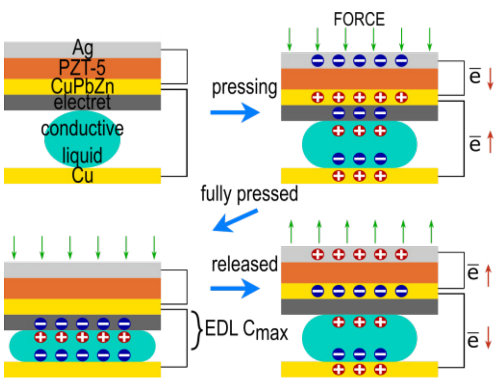

Fig. 1. Working principle of the energy harvester.

The hybrid energy harvester consists of a commercially available piezoelectric disc and a custom-designed printed circuit board (PCB) for the REWOD component. The piezoelectric disc incorporates PZT-5H ceramics, which is deposited onto a brass diaphragm (CuPbZn). In addition, the piezoelectric material is coated with silver (Ag). The REWOD component consists of a shared brass electrode coated with an electret and a counter electrode (Cu). Finally, the conductive liquid used in the system is NaCl.

Results

An experimental setup was designed to collect data on the performance of both the REWOD material and the piezoelectric material (Fig 2). The conceptual design of the harvester was tested in a frequency range from 1 to 2.5 Hz, as part of a series of parametric studies. From the results presented in Figure 3, it appears that the produced electrical power is proportional to the frequency.

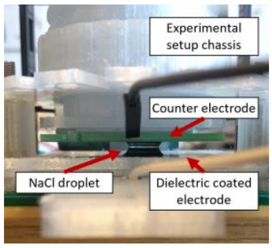

Fig. 2. Energy harvester configuration.

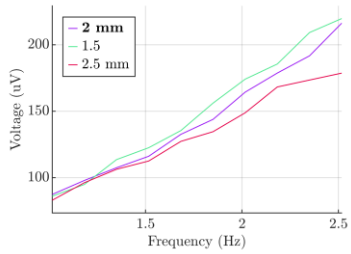

Fig. 3. Effect of initial distance between electrodes.

References

[1] Gambhir Sanjiv, S.; Ge, T.J.; Vermesh, O.; Spitler, R.; Gold Garry, E. Continuous health monitoring: An opportunity for precision health. *Sci. Transl. Med.* (2021**)**, 13, eabe5383. DOI: 10.1126/scitranslmed.abe5383

[2] Ryu, H.; Park, H.-m.; Kim, M.-K.; Kim, B.; Myoung, H.S.; Kim, T.Y.; Yoon, H.-J.; Kwak, S.S.; Kim, J.; Hwang, T.H.; et al. Self-rechargeable cardiac pacemaker system with triboelectric nanogenerators. *Nat. Commun.* (2021), 12, 4374. DOI: https://doi.org/10.1038/s41467-021-24417-w

[3] Sobianin, I.; Psoma, S.D.; Tourlidakis, A. A 3D-Printed Piezoelectric Microdevice for Human Energy Harvesting for Wearable Biosensors. Micromachines (2024), 15, 118. DOI: https://doi.org/10.3390/mi15010118

[4] Adhikari, P.R.; Tasneem, N.T.; Reid, R.C.; Mahbub, I. Electrode and electrolyte configurations for low frequency motion energy harvesting based on reverse electrowetting. *Sci. Rep.* (2021), 11, 5030. DOI: https://doi.org/10.1038/s41598-021-84414-3

[5] Huynh, D.; Nguyen, T.; Nguyen, P; Abeyrathne, C.D.; Hossain, Md.S.; Skafidas, E. Environmentally friendly power generator based on moving liquid dielectric and double layer effect. *Sci Rep.* (2016**)**, 6, 26708. DOI: https://doi.org/10.1038/srep26708