

# Emerging Nanogenerators for Rehabilitation Monitoring and Information Interaction

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## Abstract

Soft wearable devices with flexibility and stretchability attract thousands of researchers around the world. These devices can be used in health monitoring, intelligent robotic and rehabilitation training system. Emerging nanogenerators (NGs) have been studied extensively for soft wearable devices due to the advantages of easy fabrication, cost-effective, self-powered and high sensitivity in response to mechanics stimulus. Recently, the scientists have developed a flexible and stretchable nanogenerator for rehabilitation monitoring and information interaction, which is called FSDM-NG and emphasized in this commentary. The piezoelectric and triboelectric effects of the FSDM-NG have been utilized for different functions, showing some interesting and useful results to be acted as a self-powered limb motion sensor and an interface of information interaction. The purpose of the commentary is to discuss the characteristics and perspectives of NGs as self-powered wearable sensors and information interaction devices in biomedical field.

**Keywords:** Nanogenerators, Rehabilitation monitoring, Information interaction, Biosensors, Self-powered

## Introduction

Patients with limb motor dysfunction caused by trauma and stroke have poor mobility to take care of themselves, which seriously affects the quality of life of them [1]. Through reasonable rehabilitation training, the damaged motor function can be relieved to a certain extent [2,3]. In the rehabilitation training, the monitoring of limb movement can reflect the recovery state of patients' physiological function and make a systematic evaluation on the rehabilitation training effect of patients, to improve the training efficiency. At present, the rehabilitation evaluation method is mainly based on doctors' experience, using test equipment to evaluate patients' related limb movement range and other functions after rehabilitation training. However, the detection equipment is huge, heavy, solid, and hardly achieving real-time monitoring. In addition, for critically ill patients, body movement and language expression are limited. The doctors and patients cannot communicate naturally and effectively, which will cause the recovery process to be inaccurate and delayed. Therefore, the construction of portable integrated detecting system for real-time limb motion monitoring and information interaction has considerable clinical

significance in the field of rehabilitation treatment.

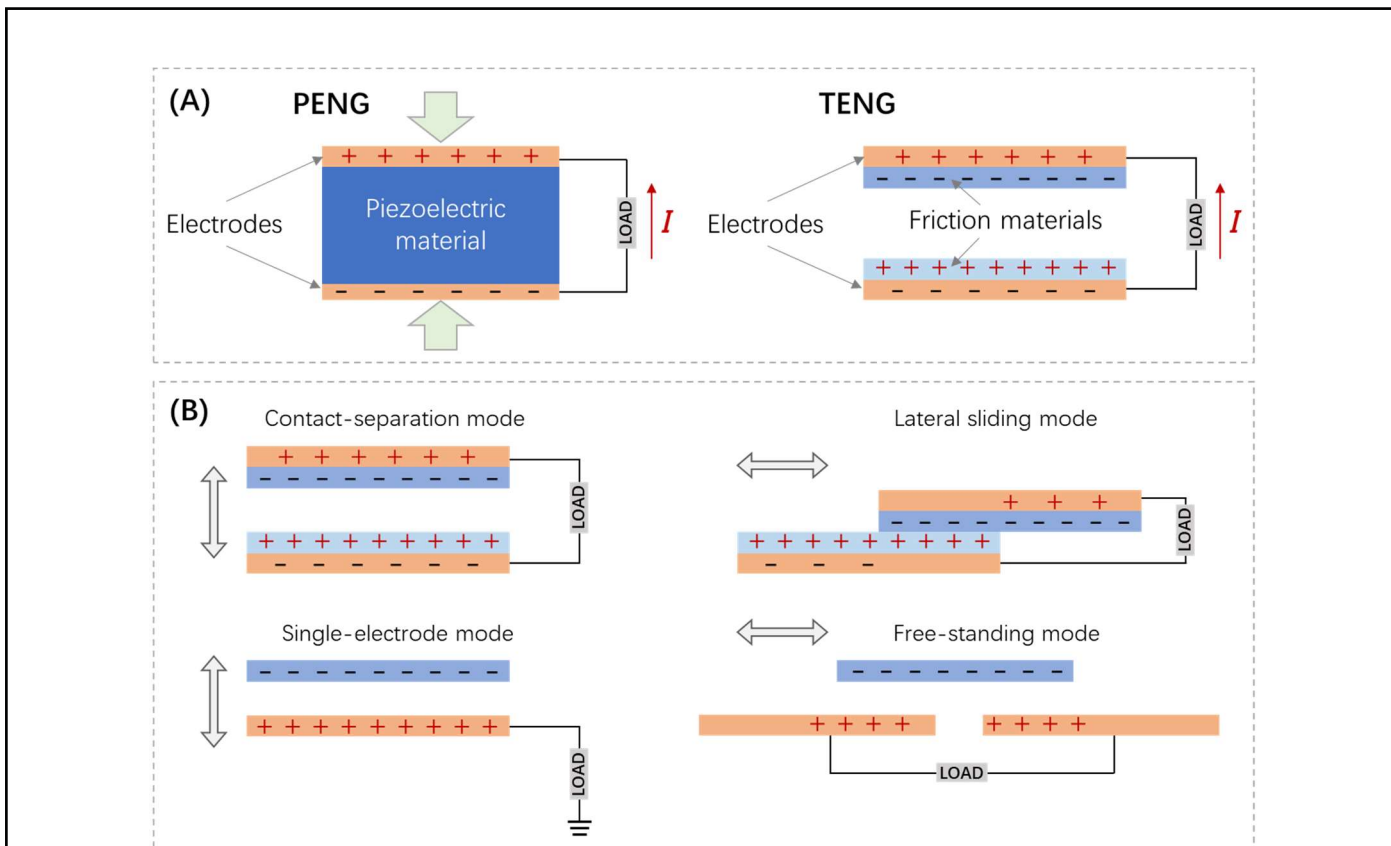
Flexible wearable electronic devices have the characteristics of lightweight, portable, deformable, stretchable, good biological safety and can withstand mechanical deformation, which are gradually emerging in clinical and daily monitoring [4-6]. They have become important sensor systems for detecting physiological signals including pulse, blood pressure, heart rate, respiration, limb motion and others related to health, which has attracted the attention of academia and industry [7-9]. However, the currently used wearable sensor systems generally need to be driven by external power supplies such as lithium batteries that need to be recharged frequently, which might bring inconvenience and greatly limits the development of flexible wearable advantages.

Self-powered devices based on the nanogenerators (NGs) have developed rapidly, which can help wearable sensors to get rid of the dependence on external power supplies. The NGs based on piezoelectric or triboelectric effect can convert mechanical energy into electricity directly, which have been used for self-powered sensors [10], electric skin [11], and biomedical applications [12-15]. The piezoelectric

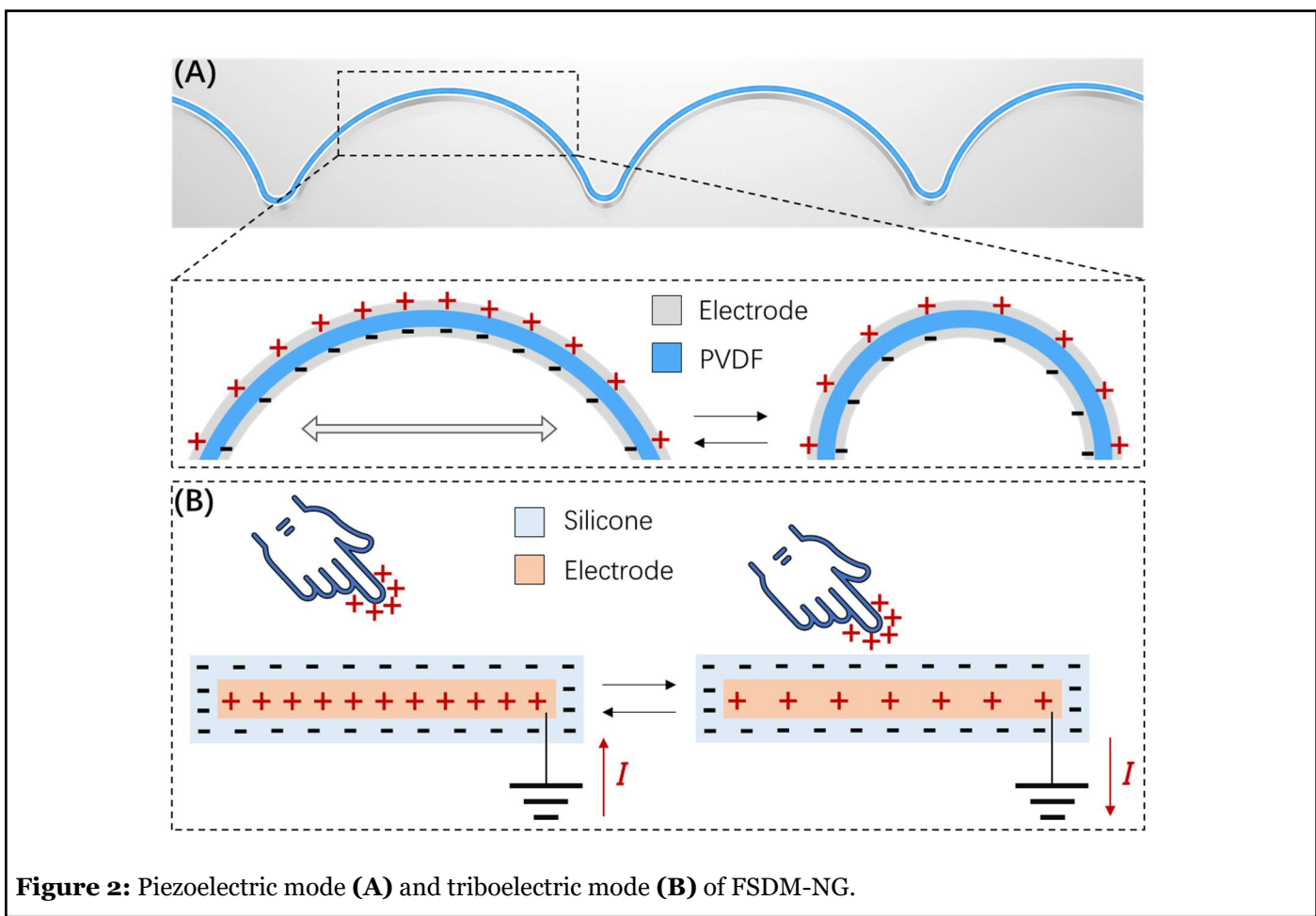
nanogenerator (PENG) was demonstrated by Zhong Lin Wang in 2006 [16]. Zinc oxide (ZnO) nanowires were fabricated into an array to convert tiny mechanical energy into electricity when bent by an external force. Besides, various piezoelectric materials such as lead zirconate titanate (PZT) [17], barium titanate ( $\text{BaTiO}_3$ ) [18] and polyvinylidene fluoride (PVDF) [19] have also been used for energy harvesting and self-powered devices. Then, the triboelectric nanogenerator (TENG) was presented by Wang's group in 2012 [20]. It is generally known that two different materials can generate triboelectric potential during contact or friction between them, which is able to drive low-power electric equipment or be acted as a self-powered sensor directly. Owing to the universal phenomenon of the triboelectric effect, we can choose suitable materials to make soft devices for applications of energy harvesting from living organisms and self-powered biosensors [21-23]. Here, we have wrote a commentary for a previous research related to a portable wearable device based on a hybrid nanogenerator for rehabilitation monitoring and information interaction. We hope this research can provide some alternative and useful perspectives for the scientists who are interested in soft wearable devices.

## Fundamentals of PENG and TENG

The basic structures of the PENG and TENG are shown in Figure 1A. The piezoelectric material is coated with electrodes on its two sides, like a sandwich structure. When the PENG is pressured, the piezoelectric potential will be generated on the surfaces coated with electrodes. Then, the PENG is stretched, and opposite piezoelectric potential appears. If we connected a load between the two electrodes, the electrons could be driven by the piezoelectric potential from one electrode to another, leading to an alternating current in the circuit [24]. To the TENG, the triboelectric charges appear on the interface of the two friction layers when they are contacted and leading to an electric potential if the two friction layers start moving away from each other. Then, the electric potential caused by the triboelectric effect can drive electrons flow in the load circuit to create a current. According to the characteristics of generation, the TENGs have four basic modes that are contact-separation mode, lateral sliding mode, single-electrode mode, and free-standing mode (Figure 1B). The significant advantages of PENG and TENG are self-powered and sensitive response; in particular, the TENG is easily fabricated and cost-effective, due to its universality of material selection.



**Figure 1: (A) Basic structures of the PENG and TENG. (B) Four basic modes of TENG.**



**Figure 2:** Piezoelectric mode (A) and triboelectric mode (B) of FSDM-NG.

### Dual Mode Nanogenerator

In the previous research [25], a flexible and stretchable dual mode Nanogenerator (FSDM-NG) coupling the piezoelectric and triboelectric effects was developed to detect the motions of finger, wrist and elbow, and send a message by Morse code. Based on the flexible tensile properties of silica gel and the piezoelectric effect of PVDF polymer materials, the researchers built an integrated flexible wearable sensor with a special wave structure through 3D printing technology. The sensor mainly displays piezoelectric mode in tensile state and triboelectric mode in the vertical contact state. The integration of the two modes can take into account the implementation of limb movement monitoring and information exchange.

### Piezoelectric Mode of FSDM-NG for Rehabilitation Monitoring

In the piezoelectric mode (Figure 2A), the elastic silica gel on the outer surface is stretched by an external force, which causes the piezoelectric strip embedded in the silica gel to produce stress and strain, and generates an electrical

signal based on its piezoelectric effect. The stretching rate of FSDM-NG can reach 33.33 %, which can meet the range monitoring of the actual limb movement. The open circuit voltage can reach about 16 V, and the short-circuit current increases with the increase of frequency, which can reach 172 nA. The influence of the tensile ratio on the output of the electrical signal is also studied systematically. On this basis, FSDM-NG can be applied to the finger joint, wrist joint and elbow joint to monitor the limb bending amplitude and the status of grasping object in real-time.

### Triboelectric Mode of FSDM-NG for Information Interaction

In the triboelectric mode (Figure 2B), the finger touches the surface of the device, and the triboelectric signal can be generated based on the basic principle of the single electrode mode TENG. The information interaction sensor is constructed by defining the “.” and “-” in the Morse code according to the electrical signals generated by the different states of the finger touching the device surface. In the experiment, we express word information such as “Nanogenerator”, which can express any information

according to the needs, especially for the construction and expression of simple logical information. This mode of information interaction only needs to touch the surface of the device in a fixed small range to transfer relevant information, which is of great significance for the rehabilitation of patients with severe limb joint movement disorder and limited language expression. Compared with the information interaction expression form of keyboard, it is more convenient and is not limited to equipment use occasions and sensor battery energy limitation, to the real-time transmission of critical doctor-patient interaction information. This work provides a new idea for the research of flexible wearable medical devices, especially in rehabilitation monitoring and information interaction. It also has potential application prospects in the field of an intelligent robot and human-machine interaction.

## Conclusion

In conclusion, emerging nanogenerators have provided plenty of interesting and useful thoughts and strategies for soft wearable sensors, biomedical devices, and techniques of information interactions. The nanogenerators based on piezoelectric or triboelectric effects can convert mechanical energy into electricity directly, suitable for being used as self-powered sensors and human-machine interaction interfaces. In the future, self-powered equipment might be a promising trend in the application scenarios of convenient daily life, rehabilitation training, smart home system and intelligent robotics.

## Conflicts of Interest

The authors have no relevant disclosures or conflicts of interest to declare.

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