Research of Wearable Triboelectric Nanogenerator for Powering and Monitoring Movements

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Abstract. Precise tracking of physical activity and sleep habits is essential for evaluating people's health, particularly in relation to upholding a healthy lifestyle, identifying illnesses early, and providing medical care. A novel technique for gathering energy is the Triboelectric Nanogenerator (TENG) characterized by high efficiency, low cost and low energy consumption, which is famous as a novel and efficient electric energy harvesting technology under different condition. This essay suggests a design that uses TENG technology to generate energy for wearable biosensor which can monitor the health condition. Subsequently, the advantages, usage and method of applications are introduced in this review. For example, TENG can be worn on different place on bodies like ankles, arms, feet, chests etc to get body system health condition monitored. Also, the essential material of the product is important. TENGs can deal with the inconvenient problem with independent energy generator using triboelectric textiles (TETs). Triboelectric textiles are synthetic materials which are thought as a unique source of energy that harvests energy from human motion. Finally, the essay suggests the working principle. Charge transfer occurs between the skin and the triboelectric textile. Electric charge transfer occurs between skin and triboelectric textiles due to the triboelectric effect.

Keywords: Triboelectric Nanogenerator, Wearable biosensor, Energy.

1. Introduction

One of society's most pressing necessities is energy. One major environmental issue is the growing use of non-renewable resources like fossil fuels. Innovative and effective technology must be created in order to harvest environmental energy and it is used for societal benefit. Even if the mechanical energy found in human walking, water flow, wind, and other natural phenomena is lost, it can be effectively transformed into electrical energy and used to power a variety of facilities, functional devices, and equipment. So Triboelectric Nanogenerator is a new energy harvesting technology that is well-known for being an innovative and effective electric energy harvesting device under many conditions. It is distinguished by its high efficiency, low cost, and low energy consumption. Triboelectric nanogenerators are a kind of technology that harvests energy that precisely converts mechanical energy from the environment, particularly low frequency energy, into electrical energy. They work by linking the effects of triboelectrification with electrostatic induction [1]. TENG is a novel energy harvesting device that operates on the fundamental ideas of electrical energy harvesting and the triboelectric effect. When two distinct triboelectric materials meet, they glide together. An electrostatic of opposite polarity is produced on the surfaces and an electron transfer takes place between the materials during mutual sliding. A vibrating membrane sits between two outer electrodes of a vertically stacked TENG. A TENG that is placed vertically was constructed to gather energy in both directions to stop vibration from causing the electrodes to adhere to one another. The electrodes had microstructures shaped like pyramids. This raises the charge density by increasing the contact area. The number of stacked layers has a proportionate effect on the output power. There is a corresponding increase in the number of layers. In the construction of TENG, elastomeric bellows are utilized as elastic elements and encapsulating components. The process of triboelectrification is widely recognized. It is a contact-induced charging process in which two distinct materials separate and acquire a charge [2]. It is well accepted that a chemical connection forms between the surfaces of two dissimilar materials when they come into touch. Next, in order to balance the electrochemical potential difference, charges are transferred from one substance to the other [3]. These charges that are transported could be molecules, ions, or electrons. Certain bonded atoms in two distinct materials tend to hold on to their additional electrons when others likely to lose them, which can lead to the material's surface to become triple charged. Tribocharges on the dielectric surface may be the source of the electron flow in the electrodes that balances the resulting potential decrease [4]. Utilizing an external pressure source, the gadget generates an output utilizing the vertical contact-detachment mechanism as its operating principle. An electric current is produced when the electrodes come into contact with external pressure and electrons are transported.

2. The Way TENG Power for the Biosensor

Wearable technology has become a significant tool for gathering and evaluating health data in recent years. It is a helpful method for early illness identification, diagnosis, and therapy. For instance, continuous monitoring of vital indicators likes heart sounds and electrocardiograms, which are crucial techniques for the identification and examination of cardiovascular disorders. Otherwise, traditional electrochemical batteries are primarily responsible for producing the electricity needed by wearable technology. The vertical contact separation mode was the mode of operation developed at first. In this mode, two polymer materials are placed face-to-face as friction layers, metal electrodes are deposited or electrode materials are applied to the backs of the two friction materials, and when the two polymers are into touch, the difference in electron attraction produces an equal amount of charges with opposing polarity on the polymer surface. The two electrodes are connected by an external circuit to form a loop. An external force separates the two materials, causing the surface charges to separate as well. This results in the formation of an electric field between the friction layers containing surface charges, which induces a potential difference at the polymer materials' back electrodes and generates a current in the external circuit. The positive and negative charges cancel when the two friction layers approach one another, eliminating the potential difference caused by the friction charges. This allows electrons to flow backwards, creating an opposite direction current in the external circuit [5]. Wearable sensors are cumbersome and inconvenient to wear because of batteries, which also need to be changed and charged frequently. Triboelectric textiles (TETs), which are an independent energy generator, can be used by TENGs to address the inconvenient issue. Synthetic materials known as triboelectric textiles (TETs) are a novel kind of energy source that derives energy from human movement. Charge transfer occurs between the triboelectric fabric and the epidermis. Skin and triboelectric textiles transfer electric charges as a result of the triboelectric effect [6]. An output voltage of about 500V can be achieved by using silicon and NI-coated polyester as two of triboelectric materials. In a two-layer TET, 140μA of short-circuit current and a voltage of more than 540 V can be produced, whereas the output voltage is 500V and the short-circuit current is 60μA 5 × 5cm2. The device is capable of illuminating 100 commercially available light-emitting diodes (LEDs). The healthcare scenario incorporating some TENG equipment is only an incidental, optional, and non-exclusive assumption established in these articles because only representative and reliable studies were selected for analysis. On their own, they don't satisfy the standards for specialized medical equipment. When being used in medicine, they frequently result in issues including rigid design, subtle effects, bulky signal processing gear (for wearables), and a dearth of experimental evidence supporting implant safety.

3. TENGS Doing Health Monitoring as Wearable Haptic Biosensor

In the rapid development of TENG-based wearable energy devices, a variety of forms and structures have been born. The wearable friction electric fabric is made of three-dimensional double-sided interlock fabric, and the fabric is a special structure of weft knitted fabric, which has good flexibility, breathability and elasticity. The two fibre materials used are cotton yarn and nylon 66, which are manufactured by three-strand and four-strand strand processes respectively, and the fibre surface of nylon 66 can be rotated with cotton yarn through silver coating and rubber coating, and the fabric can not only collect the energy of finger pressure, but also generate electricity through the stretching and compression of the fabric itself. These days, TENGs can take the position of wearable biosensors in the realm of medical surveillance. With their exceptional benefits—portable, pleasant, lightweight, flexible, high charge output, and even self-sustaining—TENGs are a suitable alternative to conventional biosensors. With these advantages, to depict the state of the body, the TENGs can be linked to various body positions. TENG presented a multilayer structure consisting of an inductively Polytetrafluoroethylene sheet treated by coupled plasma using gold electrodes on the backside and a spacer surrounded by an aluminium (Al) layer, and the assembled structure is encapsulated by a layer of polydimethylsiloxane (PDMS) measuring 1cm x 1.5cm x 0.1cm. A minimally invasive implantation of electrocardiography, femoral arterial pressure, and SEPS was accomplished in a male adult pig through the integration of a polyvinyl chloride (PVC) retractable catheter [7]. In a wearable body area network (WBAN), wearable sensor nodes are typically used to monitor physiological signals, including blood pressure (BP), body temperature, rate of heart, ECG, and body situation [6]. Considering TWB, the possibility of detecting human movement states while monitoring metabolic levels in real time, along with non-destructive and multifaceted human health assessments, could be of great benefit. In this regard, sweat as a perfect carrier contains a large number of molecular biomarkers including metabolites, hormones, electrolytes, and amino acids, making it an ideal medium for the analysis of Wearable sensors. The movement of the body stimulates the TENG to transmit electrical signals when a person runs or walks, which may suggest the condition of human movement. When sweat soaks the TENG, it activates its mode of operation. Utilizing its unique surface friction-charging effect, TENG is able to convert the concentration of biomarkers in sweat into readable electrical signals. This innovative technology opens up new possibilities for health monitoring, making it easier to access information about our bodies. The structural design of TENG is equally sophisticated. Its bottom layer is a soft layer made of PDMS, a polymer material widely used in various sensors and electronic devices. On top of its PDMS layer, the electrodes are prepared by combining two materials: Bi4Ti3O12, a ceramic material with high charge storage capacity, and PANI, a conductive polymer, which enhances both the conductivity of the electrodes and their charge storage capacity. This design not only makes the TENG more sensitive, but also allows it to excel in stability and durability. Overall, the emergence of TENG provides a new way to understand and utilize human signals, and it is expected to play an important role in a variety of fields such as healthcare, sports monitoring, and smart interaction [1, 5, 6]. To develop everlasting skin-touch textiles with high and suitable performance of a synergistic triboelectric capture layer which is equiped with cellulose-derived hydrophobic nanoparticles (HCOENPs) to mitigate degradation. This robustness was achieved by impregnation on polyethylene terephthalate (PET) knitted fabrics textiles was realized on the attachment of nanomaterials to meet the compatibility requirements for mass production [5]. The textile is combined with fabric with electrodes as well as an impermeable layer. The hydrogel electrode consists of a cellulose nanocomposite containing PANI, oxidised TEMPO CNF (TOCNF) and PVA/borax (PVAB). This unique TOCNF/PANI-PVAB hydrogel (CPPH) has excellent flexibility and self-healing ability (95% self-healing rate within 10 seconds without external stimulation) as well as high conductivity (0.6 S m-1). Subsequently, The PDMS-encased CPPH electrode was coupled with an ion-selective membrane (ISM) that could measure the concentrations of Na+, K+, and Ca2+ [5]. The flexible electrode's Na±ISM and PDMS layers functioned as the positive and negative triboelectric layers, respectively, while the TENG generated signals in a periodic contact separation mode. Foot strike is both a typical indicator of health and a rich source of energy, with 67W of potential energy for walkers. Numerous TENGs have been actively developed for the conversion of foot strike energy. Footsteps typically produce a force that is directed toward the ground, which is why TENGs that use the contact-separation mode are commonly used for motion energy conversion. Multilayer structures in particular have gained popularity because of how well they can enhance production performance. In 2016, one study reported a three-dimensional unwoven spacer material careful by TENG that utilised vertical contact. The TENG pixels have associate degree open-circuit voltage of over three V and a short-circuit current of regarding 0.3μA and therefore the output power is sixteen μW [2]. More crucially, it can be used to detect and identify human movement automatically as part of an automated monitoring system. In addition, when walking, it detects foot pressure quite sensitively. Both the output performance and the intelligent sensing capacity of this technique are great. It is possible to do an experiment that generates an electrostatic charge. Static electricity is produced when two distinct materials come into touch with one another and separate. The results of the experiment shows that the choice of material for the foot-wearing and the floor surface is the determining factor for polarity and the charge built up. Walking on a floor affects both the quantity of charge accumulation and polarity depending on the material chosen for the floor surface [1]. Determinants of polarity and amount of charge accumulation when walking on the floor. The threshold for induced discharges is approximately 2000Vvoltage of body for humans and 4000 to 6000V of body voltage for human beings [1, 5, 6]. A moist sponge that was sandwiched between the copper and PDMS surfaces of the TENG sensor allowed charge transfer by the movement of water through the sponge [4]. The sensor was positioned at the flexible bottom PVC sheet and the bladder surface. The voltage of output of the biosensor is linked to a spring-based actuator made of the shape-memory metal material called NiTi, and a voltage from outside of 4V was applied during the restoration phase. The actuator began compressing the bladder to void when the force of the liquid filling the bladder forced enough water out of the sponge. This was because the voltage output of the TENG was greater than 4V, which in turn weakened the voltage output of the TENG. Subsequently, the actuator switched back to the restoration phase [7]. Through the processes of triboelectrification and electrostatic induction, which originate from ambient mechanical motion, such as mechanical friction and vibration, oscillating motion, and expanding and contracting motion, triboelectric nanogenerators (TENGs) produce electricity. Triboelectrification and electrostatic production from surrounding mechanical motion, like rotating motion, oscillating motion, mechanical vibration, and contracting motion, is the principle about how triboelectric nanogenerators (TENGs) produce electricity. In order to obtain additional data regarding human mobility, patterned circuits were developed. The gadget can withstand extreme temperatures quite well. An arm-mounted multi-arch TENG is used to track the arm's movement. The TENG exhibits good sensitivity and can recognize basic emergency gestures (stop, turn left and turn right) as the bending angle, from 0 to 140, increases. The TENG sensor is very good at detecting variations in gait and pressure distribution [8, 9].

A sodium hydrogel TENG (SH-TENG) with a dual network polymer ionic conductor is described. High transparency of more than 95%, excellent stretchability more than 100 times (>10,000%), and strong electrical conductivity were demonstrated by the TENGs produced of this material. Stretch training belt sensor using SH-TENG-based self-power for data monitoring while performing stretches. The areas of electronic skin, medical monitoring, autonomous sensors, and human-computer interface are among the possible future uses for the suggested SH-TENG.

Another appealing option is gloves because of their inexpensive cost, low energy consumption, flexibility and resilience to wear. They are also simple to use and require little signal processing. An essay, for instance, described an affordable, glove-based, autonomous, and user-friendly HMI [6]. To strike a compromise between the need for gloves and all of the HMI's functionality, they suggested a frugal solution based on two TENG configurations. Compared with indirect fabric-based wearable TENG energy devices, direct TENGs need to be directly applied to the surface of human skin, which requires higher material and structural requirements for TENGs. The figure depicts the fabric-based TENG structure. The experiment involves first preparing and curing 0.8mm diameter silica gel. Next, the gel fibers are regularly coiled with gold-plated copper wires on their surface. The coiled silica gel fibers are then submerged in silica gel liquid for curing and encapsulation. Finally, the obtained fibers are spun into a textile structure, with the gold-plated copper wires acting as electrodes and the silica gel acting as the friction layer. This fabric-based TENG can be placed on the heel portion of a shoe sole, transferring energy from the heel to the sole during walking.

4. Conclusion

In summary, TENG as a energy generator can be equipped with wearable biosensors and put them on different body position to monitor health condition. Current challenges for efficient pedestrianisation of TENG include (1) user-friendliness, (2) high power output, and (3) mechanical robustness. The advantages that cannot be neglected include wearing comfortably, no need to charge consequently, high durability, using convenience and so on. These outstanding properties are not limited to time or places, which traditional biosensors do. You can choose when you put it on and take it off, only according to people’s needs. Furthermore, another distinguishing factor makes the biosensor remarkable is stability while it is in motion, for instance, when people run or walk TENG can fit perfectly on skin and ankle in movement. During people’s movement, it can monitor the body health condition by testing the inorganic salt element in human sweat when people move. The technology of TENG can easily reduce the difficulty for the aged to put on health monitors which means it has significant potential on clinic and medical filed. With the technology of Web of things, TENG can be watched by doctors online to protect patients from sudden decease ahead of schedule. This competitive production of power generating capability has excellent potential to continuously power running medical biomedical devices, for instance, pulse wave sensors, without relying on external batteries in the following decades.

References

[1] Cheng, Q., Sun, C., Zhang, X., et al. Short-term load forecasting model and method for power system based on complementation of neural network and fuzzy logic. Transactions of China Electrotechnical Society, 2004, 19 (10): 53-58.

[2] Xia, X., Liu, Q., Zhu, Y., Zi, Y. Recent advances of triboelectric nanogenerator based applications in biomedical systems. EcoMat, 2020, 2 (4): e12049.

[3] Ghomian, T., Mehraeen, S. Survey of energy scavenging for wearable and implantable devices. Energy, 2019, 178: 33-49.

[4] Wang, H., Cheng, J., Wang, Z., Ji, L., Wang, Z. L. Triboelectric nanogenerators for human-health care. Science Bulletin, 2021, 66 (5): 490-511.

[5] Wang, Z. L. Triboelectric nanogenerators as new energy technology and self-powered sensors–Principles, problems and perspectives. Faraday discussions, 2014, 176: 447-458.

[6] Rathore, S., Sharma, S., Swain, B. P., Ghadai, R. K. A critical review on triboelectric nanogenerator. IOP Conference Series: Materials Science and Engineering, 2018, 377: 012186.

[7] Li, R., Wei, X., Xu, J., Chen, J., Li, B., Wu, Z., Wang, Z. L. Smart wearable sensors based on triboelectric nanogenerator for personal healthcare monitoring. Micromachines, 2021, 12 (4): 352.

[8] Lu, Y., Mi, Y., Wu, T., Cao, X., Wang, N. From triboelectric nanogenerator to polymer-based biosensor: A review. Biosensors, 2022, 12 (5): 323.

[9] Wu, F., Wu, T., Yuce, M. R. An internet-of-things (IoT) network system for connected safety and health monitoring applications. Sensors, 2018, 19 (1): 21.