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Validation of devices for characterization of hybrid 3D printed embroidery TENG for energy harvesting

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ABSTRACT

A textile-based triboelectric nanogenerator (TENG) is an energy harvesting flexible and lightweight device that converts mechanical energy to electrical energy. This work presents characterization of a novel hybrid 3D printed embroidery TENG for energy harvesting. The digital embroidery part is done on Brother Embroidery Machine PR670E with polyester multifilament conductive hybrid thread (CleverTex) with a linear thread resistance of 280 Ω/m. This embroidery thread is fully compatible with the standard textile embroidery process. The thread is highly suitable for embroidery due to its very good mechanical properties and no loop formation during embroidery. These features make the thread especially suitable for high production quality. It could be used as needle thread or bobbin thread. For the preparation of the embroidery part, the polyester multifilament conductive hybrid thread is used as needle thread with 100% polyester Madeira thread as bobbin thread. These threads have non-toxic, non-skin irritation properties, which makes them suitable for smart wearable energy harvesting applications. Furthermore, these threads are coated with silicone-paraffin emulsions that improve their running during the embroidery process. Among the possible stitch types (satin, fill, prog. fill, piping, motif, cross, concentric circle, radial, spiral, flexible spiral, stippling, net fill, zigzag net fill, and decorative fill), fill stitch with medium stitch density and 4.5 lines per mm has been used to develop this energy harvesting sample. The 3D printed textile fabric is prepared with extremely flexible filament with a tensile elongation at break of 1400%. The output voltage is 200 V and 103 V for tapping and friction characterization, respectively.

Keywords
hybrid nanogenerator,
flexible filament,
3D printing,
embroidery,
tapping characterization,
conductive multifilament,
hybrid yarn

1 Introduction

Triboelectric nanogenerators (TENGs) couple triboelectric effect and electrostatic induction to convert mechanical energy into electricity; because of the benefit of fabrication, tremendous progress has been created since the first discovery in 2012 [1,2]. The triboelectric effect is everywhere in our daily life and results from two different materials coming into contact. Sometimes, it is considered an adverse consequence due to a spark near the electronics parts [3], but these generated charges could also be collected to harvest energy [4-6]. The triboelectric nanogenerator is one of the promising candidates for powering wearable electronics with flexibility, lightweight and good performance [7,8]. There are mainly two categories of TENG, i.e. fiber-based TENG and fabric-based TENG [9, 10]. Materials that are used to develop (TENGs) have received special consideration for wearable applications. TENGs are also used in combination with other energy harvesting materials [2, 11]. A triboelectric nanogenerator was reported to be made with embroidery on the textile substrate using the pile embroidery in order to have a rough and high surface area to get a high result voltage of 113 V [12]. There is an investigation concerning the result of textile process technique (weaving, knitting, sewing, embroidery, etc.) and structure pattern on the TENG's output performance [13].

There are different modes of triboelectric nanogenerators that are used to harvest energy, offering a variety of choices of application areas on harvesting energy from human motion [14-16]. There are devices having different options to characterize the electrostatic or triboelectric behavior of textile materials [17-19]. On a fundamental level, any material with a particular charge density can be utilized to develop a TENG, which brings about a broad scope of materials at the furthest edges of the triboelectric series [20-22]. A 3-dimensional ultra-flexible TENG was reported to harvest biomechanical energy [23]. The all-printed triboelectric nanogenerator (AP-TENG) is a combination of the advantages of 2D and 3D printing innovations. The primary edge is framed by 3D printing as a center shell structure, which successfully changes over outside vibrations into consistent sliding movement. An AP-TENG reported in the literature produces a high momentary voltage of 98.2 V [22]. Triboelectric generators and sensors have large potential as self-controlled wearable gadgets for energy collecting biomechanical motions. There are four different basic modes of triboelectric nanogenerators; vertical contact separation mode, single electrode mode; contact sliding mode, and freestanding mode, as shown in Fig. 1. These modes are also applicable for tapping and sliding devices. The vertical contact separation mode and single electrode mode are for the tapping motion, and contact sliding and freestanding mode are for the sliding device.

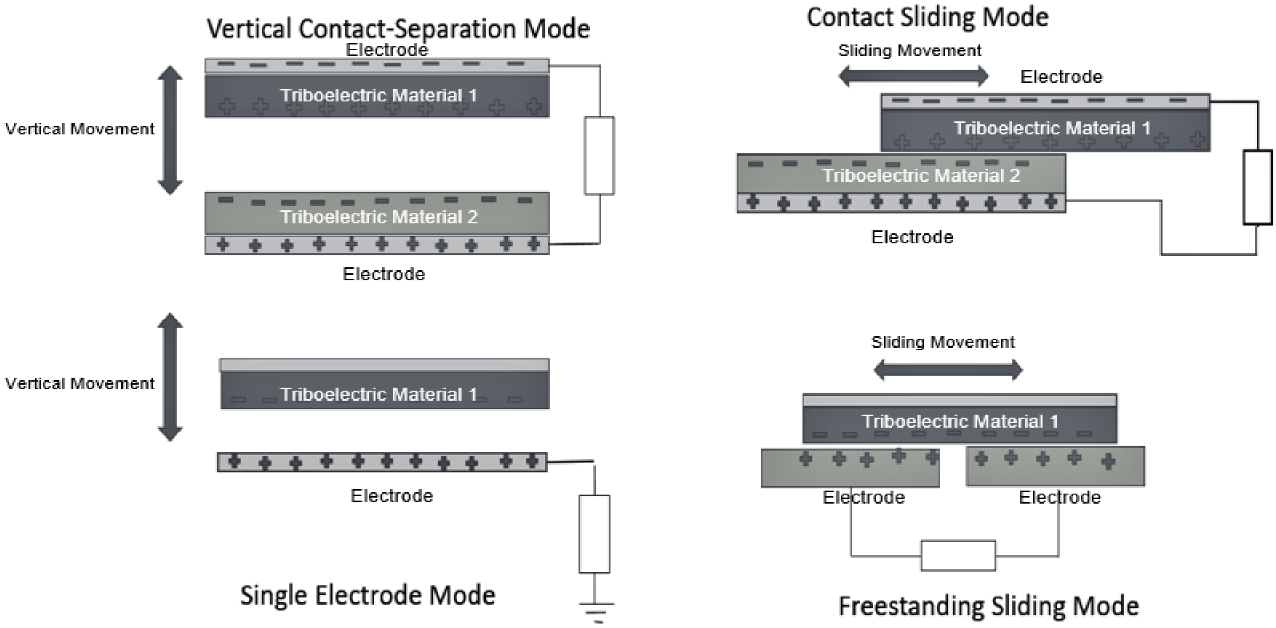


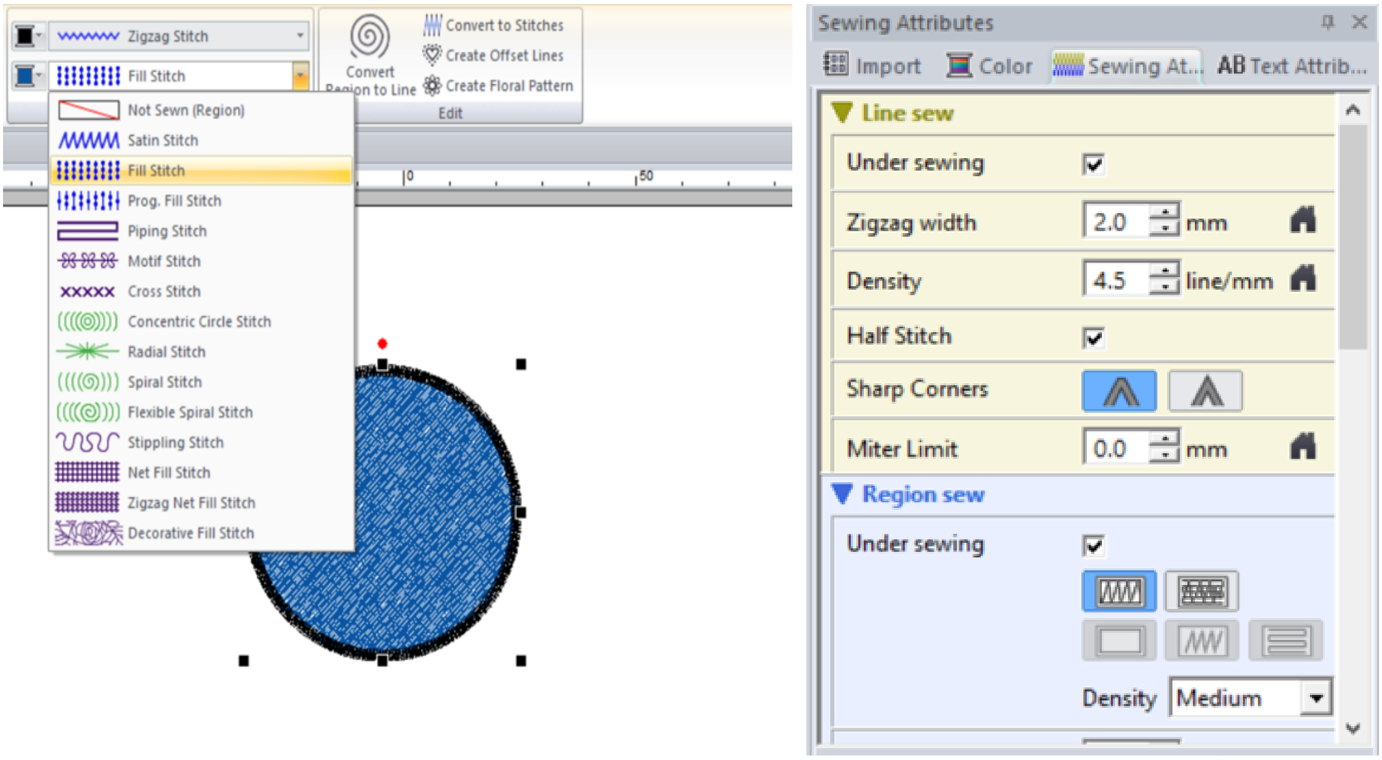
Fig. 1 Four fundamental modes of triboelectric characterization [17].

In this study, we use both generation modes of triboelectric charges to characterize the samples. We develop hybrid materials and a technology-based triboelectric nanogenerator. We use the commercially available yarn with a commercially available embroidery machine, which is suitable for making an exciting fabric design and harvesting energy. 3D printing filament that is used for triboelectric generator is good material for both creating the insole and making print on the textile substrate, so it is very useful for harvesting energy not only from sliding motion if it is attached to wearables, but it could also harvest energy from tapping motion if it is used as an insole.

2 Materials and methods

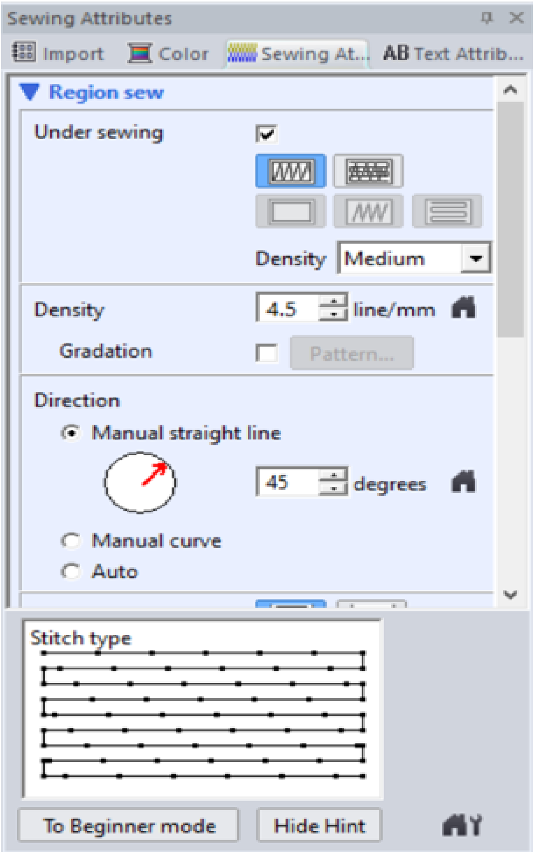
This TENG has been made with an embroidery machine and 3D printing on a textile substrate. The embroidery machine PR 670E has been used to develop the embroidered sample. This machine has six needle heads and can sew different embroidery patterns. There are different stitch types, e.g., satin, fill, prog. fill, piping, motif, cross, concentric circle, radial, spiral, flexible, stippling, net fill, zigzag net fill, zigzag, and decorative fill stitch.

The sample for the energy harvesting was made with polyester multifilament conductive hybrid thread as needle thread and 100% polyester Madeira yarn as bobbin thread with fill stitch. The manufacturer of the conductive yarn is CLEVERTEX®. For the upper side of the sample, the stitch length was 2 mm with a line density of 4.5 lines per mm. The line density was medium for the under sewing with 4.5 lines per mm at a 45° angle. The sample was prepared at 700 rounds per minute, showing the good strength and running of the stitching thread used for the embroidery. Fig. 2 shows the embroidery attributes.



(a) (b)

Fig. 2 Cont.



(c)

(d)

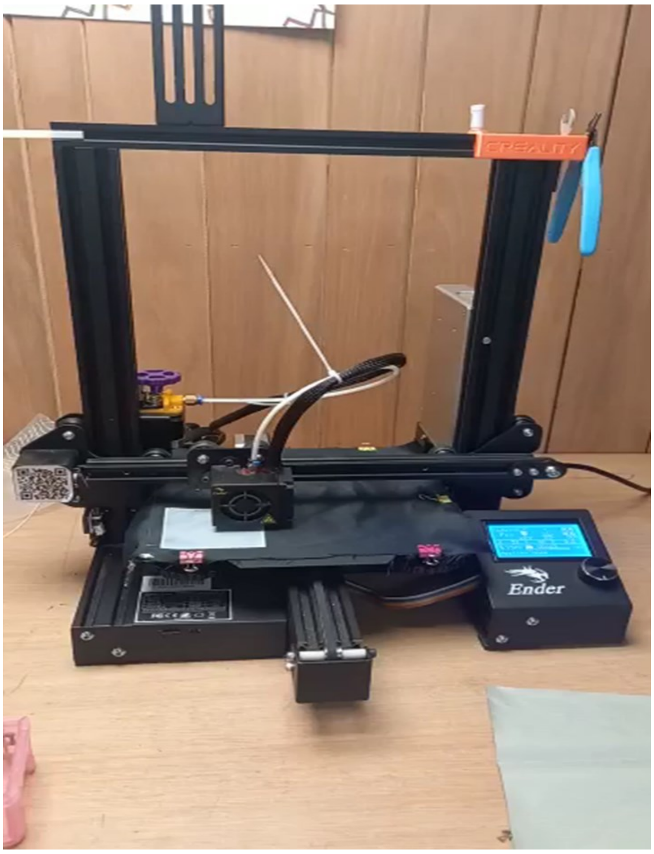
Fig. 2 (a) Embroidery attributes – selection of stitch type; (b) sewing attributes – sewing stitch length of 2 mm, stitch density medium with 4.5 lines per mm; (c) under sewing attributes – medium stitch density, 4.5 lines per mm at an angle of 45 degrees; (d) embroidered sample with conductive yarn to harvest energy.

3D printing on the fabric is performed with Filaflex, a high flexible and elastic material with a tensile elongation at break of 1400%. Flexible filament printing is possible at lower temperatures (215 – 225 °C), and the filament must be moisture-free. The flexible filament also has excellent print bed adhesion, so they do not require a heated print bed, tape, lacquer, or spray adhesive. In addition, it is odorless and resistant to solvents such as acetone or petrol. Since it is a non-toxic material, it can also contact the skin.

The filament can be used for insoles, especially orthotic insoles. Another application of this flexible filament is textile parts and accessories: clothing, textile fabrics, prints on garments, bags, etc. The printing speed required is 20-30 mm/s with an optimal layer height of 0.2 mm. It has a remarkable hydrolysis resistance, high resistance to bacteria, and low-temperature flexibility properties.

Fig. 3 shows the 3D printing on the textile substrate. Two different devices were used to characterize the samples for the tapping and sliding characterization at a frequency of 2 Hz.

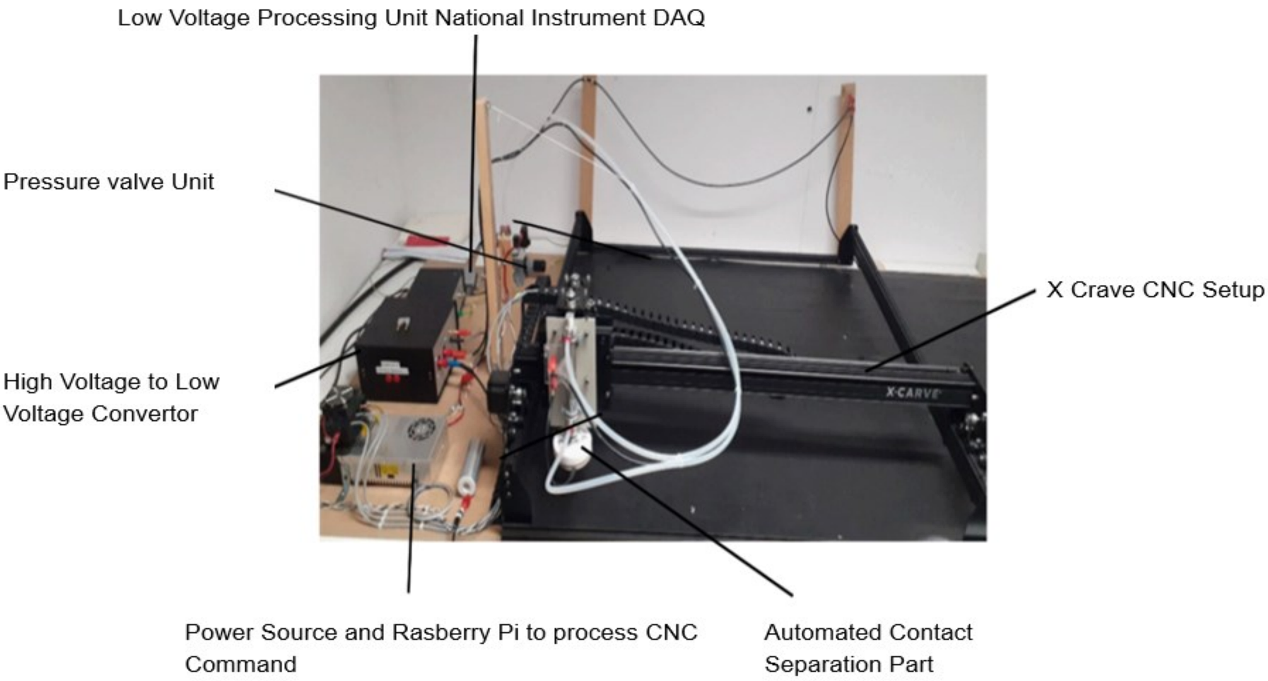
For the tapping device, the dwell time, contact time, and up was 200 ms, 250 ms, 50 ms, and for the sliding device, a frequency of 2 Hz is controlled with a variable power supply (24 V required for 2 Hz). Fig. 4 shows the energy harvesting TENG with characterization devices for tapping and lateral sliding characterization.



(a)

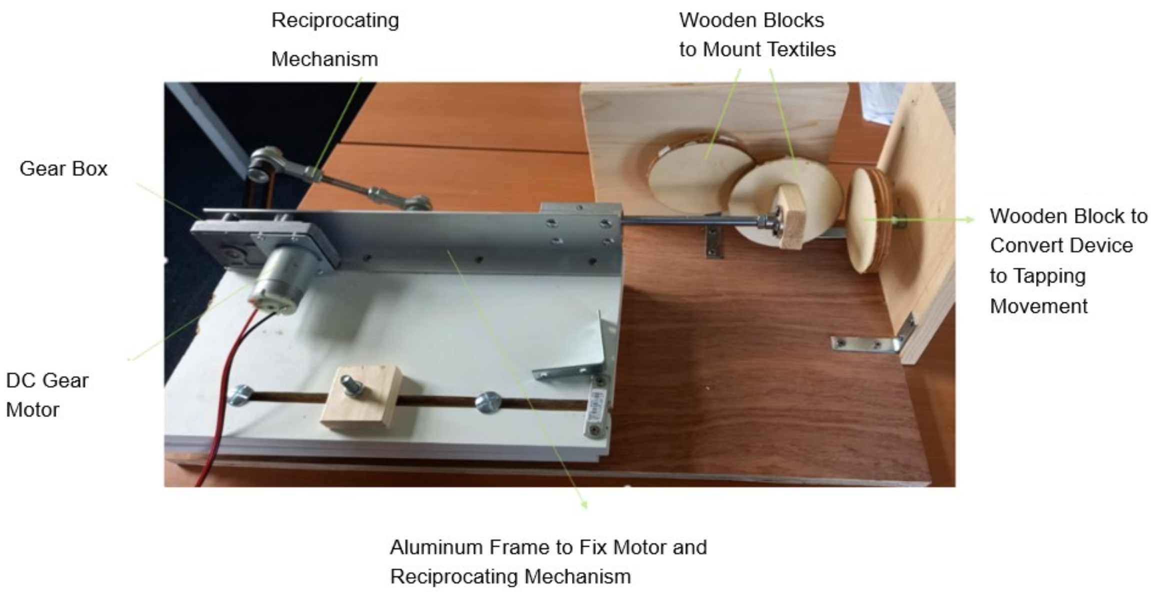
(b)

Fig. 3 3D printing on the textile substrate. (a) Filaflex is used to print on the textile substrate with flexible and elastic materials with a tensile elongation at break of 1400% (b) flexible, lightweight and soft 3D printed sample.



(a)

Fig. 4 Cont.

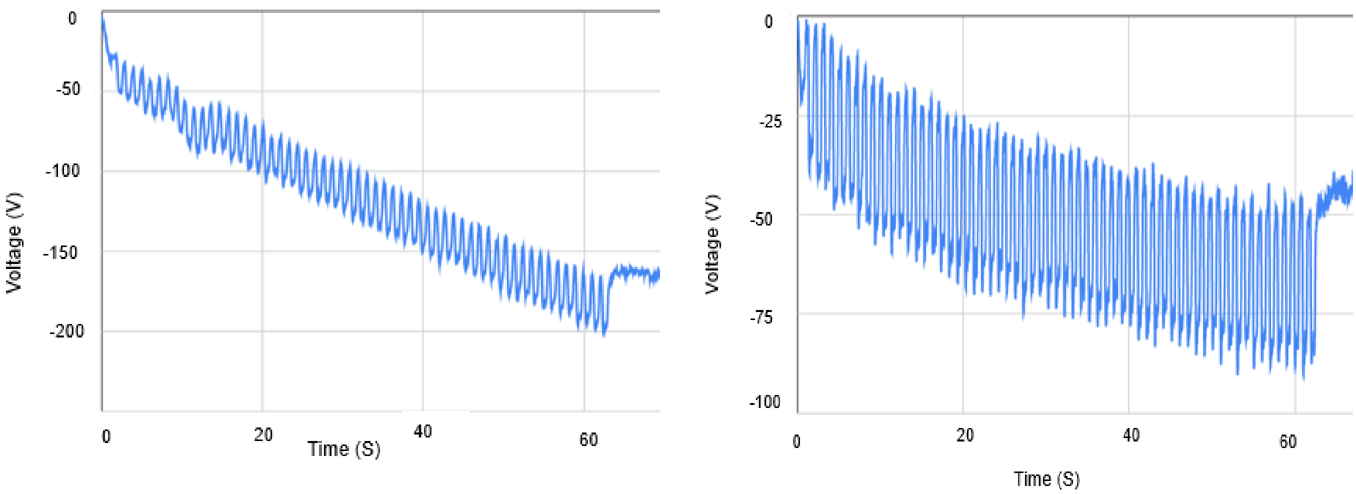


(b)

Fig. 4 Energy harvesting TENG with characterization devices: (a) Tapping characterization device for TENG; (b) lateral sliding characterization device for TENG.

3 Results and discussion

Fig. 4 shows the TENG's output voltage of the tapping and sliding mode. For the tapping characterization, the generated voltage is increased over time up to 200 V. The overall voltage waveform is in negative direction due to dominating negative triboelectric behavior of 3D printing filament. In contrast, for the sliding device, the slope of the voltage vs. time is not much steeper than in tapping mode, with a generated maximum of 98 V. The measured output power of the TENG is 400 mW and 96 mW at the resistance of 100 kΩ resistance, respectively. The output power for the tapping mode is higher, reflecting the printed dot-structure to respond more to pressing than to sliding.



(a) *(b)*

Fig. 5 Output voltages of the tapping and sliding mode of TENG: (a) tapping characterization voltage versus time; (b) lateral sliding characterization voltage versus time.

4 Conclusions

We presented a hybrid TENG, developed from a conductive polyester multifilament conductive hybrid thread (CleverTex) and 3D printing of highly flexible and elastic material with a tensile elongation at break of 1400%. Both triboelectric fabrics have good flexibility and softness after the embroidery and printing. The triboelectric performance measured on tapping and friction devices at a frequency of 2 Hz gave output voltages of 200 V and 98 V, and the measured output power was 400 mW and 96 mW at a resistance of 100 kΩ, respectively.

Author Contributions

Author contributions statement: H. R. Tahir: conceptualization, methodology, validation, writing – original draft preparation; B. Malengier: conceptualization, methodology, software, supervision; C. Hertleer: visualization, project administration; L. Van Langenhove: Software, supervision, project administration, funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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