Heliyon 10 (2024) e30845

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

A wearable flexible triboelectric nanogenerator for bio-mechanical energy harvesting and badminton monitoring

Min Wu, Zheng Li *

Physical Education Department, Dalian Ocean University, Dalian, 116023, Liaoning, China

ARTICLE INFO

Keywords:
Triboelectric nanogenerators (TENGs)
Non-woven fabric
Smart sports
Badminton monitoring
Wearable electronics

ABSTRACT

Recently, textile materials used for wearable flexible sensors have received much attention. Wearable textile based triboelectric nanogenerator (TENG) not only has unique advantages in mechanical energy harvesting, but also has application value in the direction of motion sensing. Here, we proposed a non-woven fabric triboelectric nanogenerator (NW-TENG) for mechanical energy harvesting and badminton monitoring. The non-woven fabric play the role of positive triboelectric, and the fluffy fiber structure endows NW-TENG with a sensitive response to pressure. The pressure sensing sensitivity of NW-TENG sensor can reach 1.22 V N^{-1} (Pressure range: 0–7 N) and 0.18 V N^{-1} (Pressure range: 8 N–55 N). Furthermore, the NW-TENG can be installed on the body joints of badminton players for analyzing joint movements, thereby achieving data-driven badminton training and facilitating the evaluation of training effectiveness. This research provide a new path to promote TENG to the badminton monitoring field.

1. Introduction

With the rapid popularization of mobile portable electronic devices, higher requirements have been put forward for advanced flexible sensors, especially sensor devices with self-powered functions [1,2]. In recent years, wearable sensors with electronic skin features have received widespread attention, and these sensing devices have potential application value in fields such as human posture monitoring [3], biomedical diagnosis [4], smart sports equipment [5], and robot skin [6]. According to different sensing styles, including temperature [7], optics [8], mechanics [9], magnetism [10], humidity [11], and gas [12], wearable flexible sensors can convert this physical information into visual electrical signals for information processing, communication, and storage analysis. It is interesting that triboelectric nanogenerator (TENG), as a new type of mechanical energy generation technology, can harvest micro-mechanical energy from various small movements [13–21]. Meanwhile, wearable TENG based on textile film has advantages such as lightweight, flexibility, and strong flexibility, especially being easily compatible with the human body and exhibiting a good service life [22–24]. Hence, wearable TENG devices have strong advantages in human motion monitoring and sensing, as well as capturing mechanical energy during human motion, making them an important candidate for future wearable sensors [25].

Recently, research on TENG textiles that are flexible, durable, biocompatible, and stretchable has attracted much attention [26,27]. This type of textile TENG has become a wearable device for human motion monitoring and energy harvesting owning to simple preparation, low-cost, and strong environmental adaptability [28]. To optimize the performance and functionality of TENG, its application range is expanded by integrating shape memory [29], self-healing [30], super elasticity [31], and electroluminescence

* Corresponding author.
E-mail addresses: wumin@dlou.edu.cn (M. Wu), lizheng@dlou.edu.cn (Z. Li).

https://doi.org/10.1016/j.heliyon.2024.e30845
Received 6 February 2024; Received in revised form 6 May 2024; Accepted 7 May 2024
Available online 7 May 2024

technologies [32]. However, as wearable electronic devices typically come into contact with human skin, factors such as device breathability, skin compatibility, and healthy materials need to be considered. Therefore, exploring textile TENG suitable for human motion monitoring will help promote its application. With the successive hosting of the Olympic and Winter Olympics, people's attention to sports is gradually increasing. More emphasis is placed on how to improve the athletic performance of athletes. Sports equipment is an important factor that affect the athletic of competitive athletes, especially in badminton [33,34]. In the past, athletes were unable to record their hitting position and strength well during training, resulting in coaches being unable to develop personalized training plans based on the actual hitting situation of the athletes. The introduction of self-powered sensors can be used to monitor the movement of athletes, collect shortcomings in the training process of athletes, and help coaches develop more comprehensive training plans for different athletes. Hence, it is very meaningful to promote the entry of textile TENG into the badminton industry for monitoring.

In this work, we designed a non-woven fabric triboelectric nanogenerator (NW-TENG) for mechanical energy harvesting and badminton monitoring. The non-woven fabric has advantages such as high strength and durability, breathability, simple manufacturing process, easy drying and production, skin friendliness, and environmental protection. The non-woven fabric and polytetrafluoroethylene (PTFE) form the triboelectric pairs. The non-woven fabric play the role of positive triboelectric layer and the PTFE film serves as the negative triboelectric layer. The aluminum foil is used for conductive electrode. As self-powered pressure sensor, the NW-TENG exhibits different sensitivities in different pressure ranges. In detail, when the pressure is within the range of 0–8 N, the pressure sensing sensitivity of NW-TENG can reach 1.22 V N^{-1}. When the pressure is within the range of 8 N–55 N, the pressure sensing sensitivity of NW-TENG can reach 0.18 V N^{-1}. Furthermore, the NW-TENG can be installed on the body joints of badminton players for analyzing joint movements, thereby achieving data-driven badminton training and facilitating the evaluation of training effectiveness.

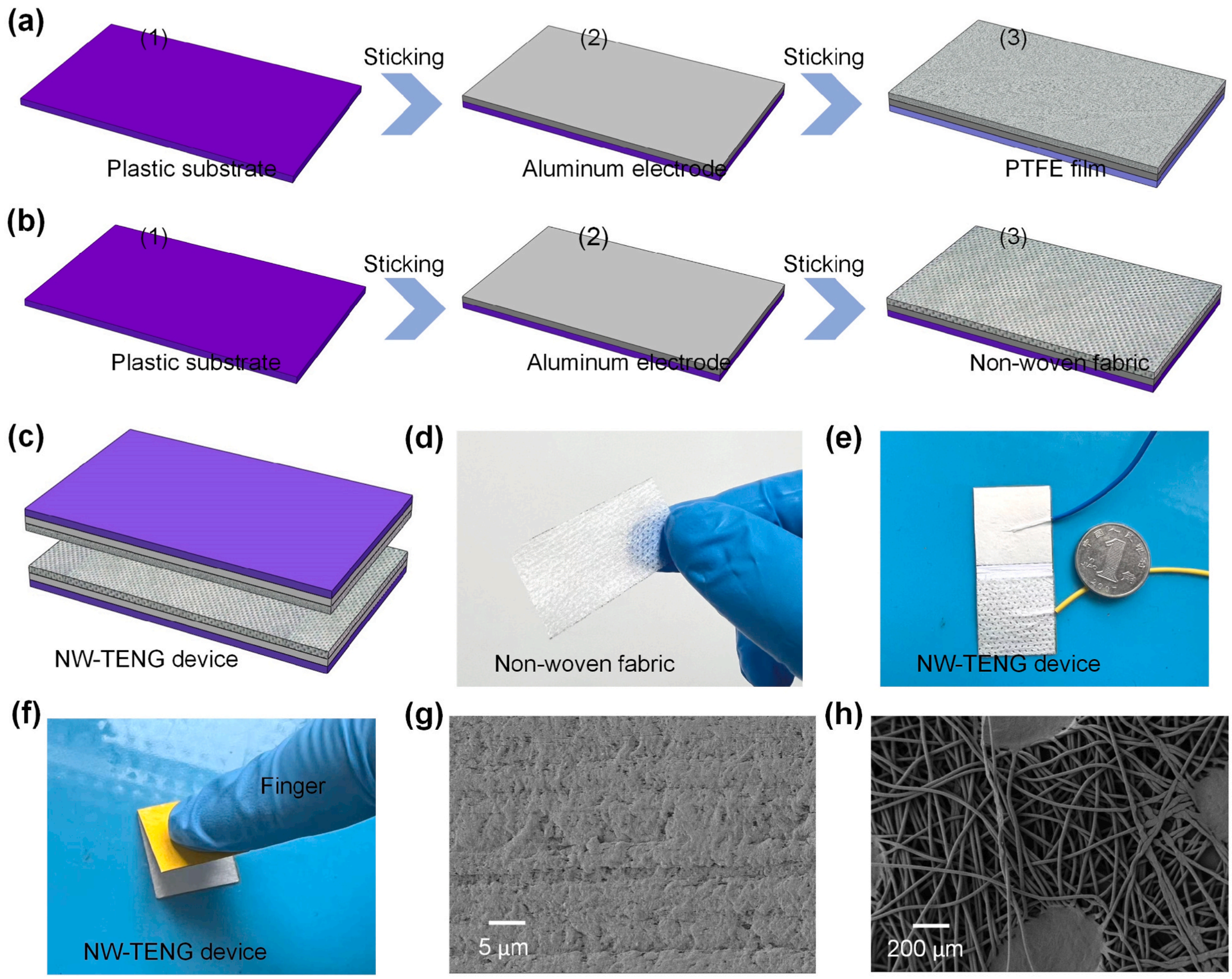

Fig. 1. (a1-a3) The preparation process of negative triboelectric layer. (b1-b3) The preparation process of positive triboelectric layer. (c) The structural design diagram of NW-TENG device. (d) The photograph of non-woven fabric sheet. (e) The photograph of NW-TENG. (f) Schematic diagram of NW-TENG's working mode. The SEM image of (g) PTFE film and (h) non-woven fabric film.

2. Experiments

2.1. Materials

The PTFE film (thickness: 50 μm) was bought from Shanghai Minyin New Materials Technology Co., Ltd, China. The plastic substrate was obtained from Jiangsu Xufu New Materials Co., Ltd, China. The non-woven fabric was purchased from Zhengzhou New Year Interlining Hot Melt Adhesive Co., Ltd, China. Double-sided adhesive can be purchased from online shopping malls.

2.2. Preparation of the NW-TENG device

In this design, the NW-TENG consists of two parts (positive triboelectric component and negative triboelectric component), and the detailed fabrication process of two parts were presented in Fig. 1(a and b). Firstly, cut the plastic into two pieces of substrate with dimensions of 2 cm × 2 cm (Fig. 1(a1, b1)). Then, stick aluminum foil on their surface with double-sided adhesive as conductive electrodes (Fig. 1(a2, b2)). Immediately, paste PTFE film and non-woven fabric film respectively on the surface of aluminum foil as triboelectric layers (Fig. 1(a3, b3)). Finally, assemble two components into NW-TENG for harvesting various mechanical energy (Fig. 1(c)). Moreover, Fig. 1(d) illustrates the picture of non-woven fabric film (thickness: 110 μm). The non-woven fabric film has advantages, such as lightweight, flexibility, and good breathability. The photograph of NW-TENG was illustrated in Fig. 1(e). The NW-TENG can obtain the mechanical motion received into contact-separation motion between the two triboelectric layers of NW-TENG (Fig. 1(f)).

2.3. Characterization and measurements

Moreover, the micro-nano structures on PTFE surface can be observed according to the scanning electron microscopy (SEM) image

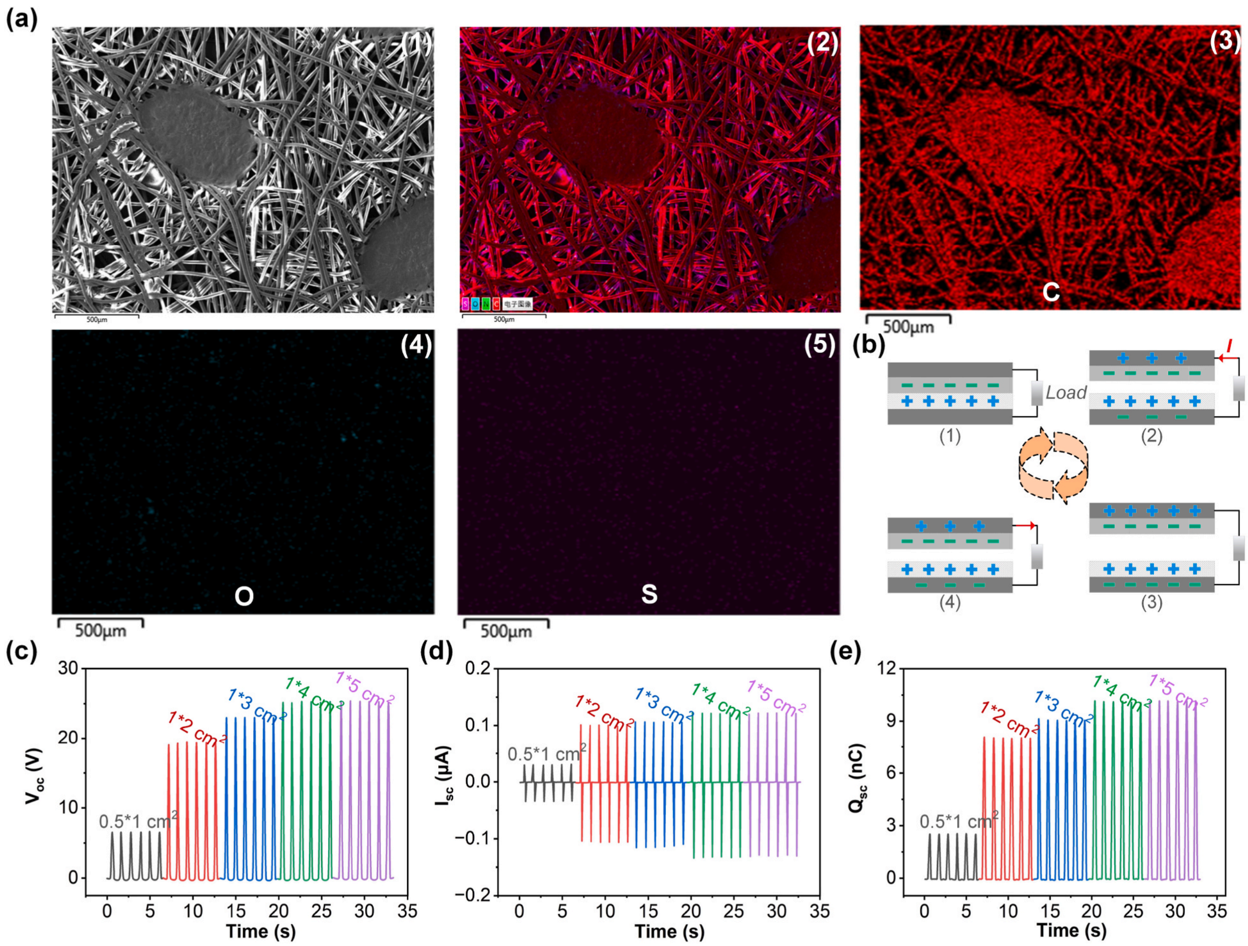

Fig. 2. (a1-a5) The EDS elemental analysis of non-woven fabric film surface. (b1-b4) The operating mechanism of NW-TENG. The (c) V_{oc}, (d) I_{sc}, and (e) Q_{sc} of NW-TENG under different sizes from 0.5 cm × 1 cm–1 cm × 5 cm.

in Fig. 1(g). The rough surface texture of PTFE film can help to improve the triboelectric efficiency. Besides, based on the non-woven fabric surface SEM image in Fig. 1(h), non-woven fabric consist of many small fibers, which provide higher efficiency for triboelectric and indicate good breathability, making them suitable for use as wearable electronic devices for the human body. Fig. 2(a1-a5) illustrate the surface energy dispersion spectroscopy elemental analysis of non-woven fabric film, and the surface of the non-woven fabric film is uniformly distributed with elements such as C, O, S, etc. Furthermore, the electrometer (Keithley 6514) was used to measure the V_{oc}, I_{sc}, and Q_{sc} of NW-TENG device. The mechanical vibrator was used to provide continuous and stable power for NW-TENG.

3. Results and discussion

3.1. The working mechanism of NW-TENG

Fig. 2(b) displays the operating mechanism of NW-TENG. Firstly, when PTFE film and non-woven fabric film come into contact with each other under mechanical force, electronic transitions occur between the PTFE film and non-woven fabric film, resulting in an opposing distribution of positive and negative charges (Fig. 2(b1)). When the mechanical force is withdrawn, under the elastic action of NW-TENG itself, PTFE film and non-woven fabric film separate, and electrons located at the back electrode of PTFE film will flow towards the back electrode of non-woven fabric film, causing current to be generated in the circuit (Fig. 2(b2)). When the separation distance between PTFE film and non-woven fabric film reaches its maximum, the current in the circuit will become zero due to the maximum potential difference between PTFE film and non-woven fabric film (Fig. 2(b3)). When PTFE film and non-woven fabric film approach again under mechanical force, electrons located at the back electrode of non-woven fabric film will flow back into the back electrode of PTFE film, producing a reverse current (Fig. 2(b4)). From the results in Fig. 2(c–e), the electrical output of NW-TENG represents an upward trend, which confirms that increasing device size is an important way to improve performance. The size of TENG devices will influence their effective contact area. The larger the contact area, the more triboelectric charges it generates, which will lead to higher electrical output.

In general, the separation distance between triboelectric films usually influences the potential difference of TENG device, which in turn affects the electrical performance of TENG device. Based on results in Fig. 3(a)–as the separation distance between PTFE film surface and non-woven fabric film surface improves from 1 to 6 mm, the V_{oc} of NW-TENG grows from 14.57 V to 62.55 V. The separation distance between PTFE film surface and non-woven fabric film surface will influence the V_{oc} of NW-TENG devices, and the larger the separation distance, the greater the V_{oc}. The research indicates that the I_{sc} of NW-TENG can increase from 0.076 μA to 0.292 μA as the separation distance grows (Fig. 3(b)). According to results in Fig. 3(c), the Q_{sc} of NW-TENG can rise from 3.69 nC from 15.56 nC when the separation distance improves from 1 to 6 mm. The increase in separation distance enhances the efficiency of charge transfer in the back electrode of PTFE film and non-woven fabric film. Besides, the magnitude of the contact force can influence the contact efficiency of the triboelectric material surface. Hence, the NW-TENG performance under different contact forces was investigated. Based on results in Fig. 3(d), when the contact force grows from 1 N to 10 N, the V_{oc} of NW-TENG can increase from 3.87 V to 32.79 V. The increase in contact force can drive PTFE film to have more thorough contact with non-woven fabric film, leading to an

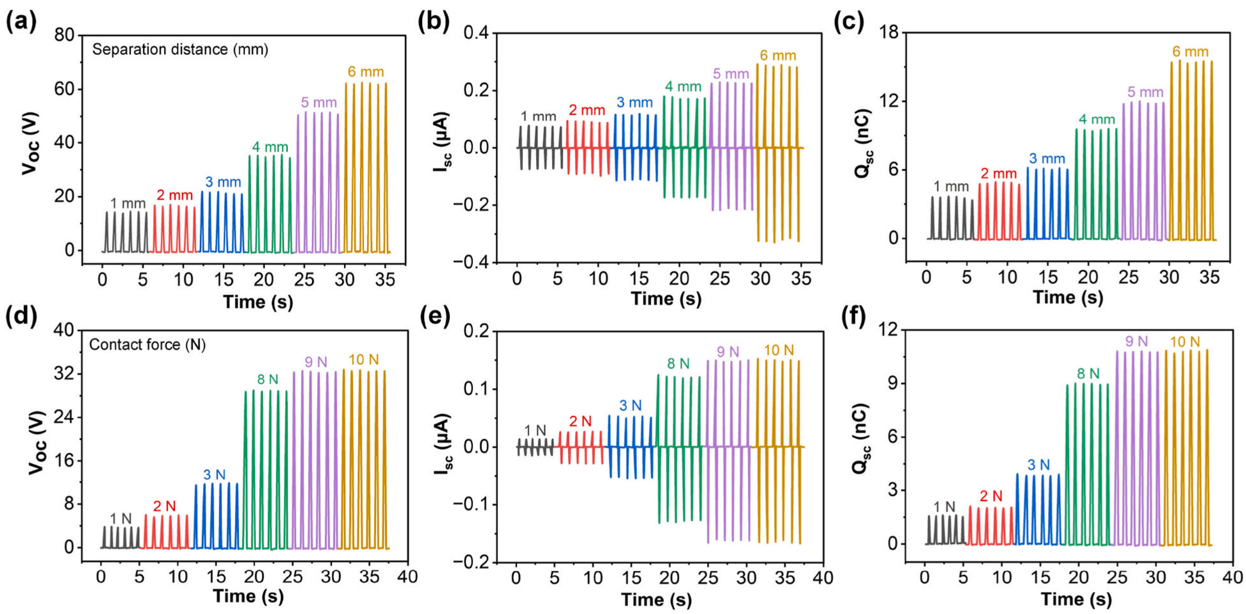

Fig. 3. The (a) V_{oc}, (b) I_{sc}, and (c) Q_{sc} of NW-TENG under different separation distances. The (d) V_{oc}, (e) I_{sc}, and (f) Q_{sc} of NW-TENG under different forces.

increase in V_{oc} of NW-TENG. Fig. 3(e) illustrates the trend of I_{sc} variation under different contact forces from 1 N to 10 N. The I_{sc} of NW-TENG represents an upward trend as contact force increases. But, when the contact force arrives at a certain extent, the upward trend of V_{oc} and I_{sc} slows down and tends to stabilize, which is due to the stabilization of contact efficiency. The same influence occurs on Q_{sc}, when the contact force expends from 1 N to 10 N, the Q_{sc} of NW-TENG increase from 1.61 nC to 10.63 nC, as illustrated in Fig. 3(f). Due to the porous structure of non-woven fibers, as pressure increases, the surface fibers of the non-woven fabric are compressed to form a more sufficient triboelectric effective area, leading to improved electrical output. Based on this principle, combined with experimental testing, it can be observed that the output performance of NW-TWNG gradually improves as the pressure increases from 1 N to 8 N. When the pressure exceeds 8 N, due to the compression of the non-woven fabric to its limit, the effective frictional area reaches its maximum value, and hence, the electrical output of NW-TENG tends to stabilize.

Furthermore, mechanical frequency is also an important factor affecting the output of TENG devices. In detail, when the mechanical motion frequency driving NW-TENG increases between 1 Hz and 5 Hz, the V_{oc} peak value of NW-TENG exhibits stable characteristics according to results in Fig. 4(a), because high mechanical frequencies cannot increase the potential difference between two triboelectric layers. However, for I_{sc} of NW-TENG, an increase in mechanical motion frequency will increase the charge transfer rate, thereby causing an impact on I_{sc}. When the mechanical motion frequency increases from 1 Hz to 5 Hz, the I_{sc} of NW-TENG will grow, as shown in Fig. 4(b). Like V_{oc} of NW-TENG, mechanical motion frequency does not have an impact on Q_{sc}, as displayed in Fig. 4 (c). Considering the special surface morphology and fluffy material of non-woven fabric, NW-TENG exhibits a special response to pressure. From the results in Fig. 4(d)–as self-powered pressure sensor, the NW-TENG exhibits different sensitivities in different pressure ranges. In detail, when the pressure is within the range of 0–8 N, the pressure sensing sensitivity of NW-TENG can reach 1.22 $V N^{-1}$. When the pressure is within the range of 8 N–55 N, the pressure sensing sensitivity of NW-TENG can reach 0.18 $V N^{-1}$, which is superior to the previous works of self-powered pressure sensors [35–37]. Moreover, due to its high-strength textile fibers, NW-TENG has excellent reliability. From stability experiment results in Fig. 4(e), the output voltage of NW-TENG remains stable after 50000 working cycles. Also, the NW-TENG can still maintain good output performance after undergoing various extreme deformations, according to Fig. S1 of **Supporting Information**. The micro-energy generated by NW-TENG can be stored in small capacitors through rectification circuits. According to results in Fig. 4(f), the NW-TENG charges capacitors with lower capacitance values, resulting in higher voltage values. The increase in relative humidity will reduce the electrical output of NW-TENG, as humidity will cause loss of triboelectric charges, according to Fig. S2 of **Supporting Information**. Moreover, low temperature will cause a decrease in the output performance of NW-TENG, as it will reduce the transfer effect of triboelectric charges, according to Fig. S3 of **Supporting Information**.

Badminton sports have the characteristics of fast movement speed, multiple changes in the ball path, and strong hitting skills. Due to objective factors such as limited exercise time and population, it is a widely used whole-body exercise. Long term badminton is a popular fitness activity, which helps to increase height, relax the neck, shoulders, and spine, relieve eye fatigue, and promote physical and mental development. To scientifically enhance the value of badminton fitness, it is necessary to accurately understand the characteristics of sports and monitor their exercise volume. Hence, we can promote NW-TENG to badminton sports monitoring, which not only plays a role in energy harvesting, but also plays its sensing and monitoring function, as expressed in Fig. 5(a). NW-TENG has

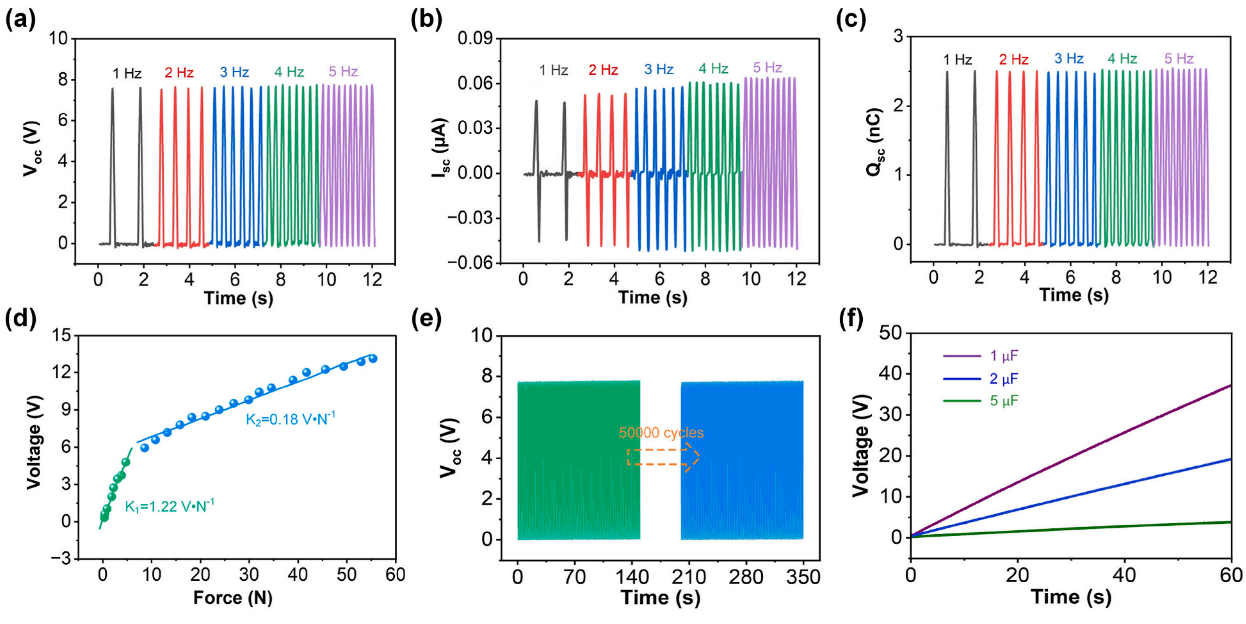

Fig. 4. The (a) V_{oc}, (b) I_{sc}, and (c) Q_{sc} of NW-TENG under various mechanical motion frequencies. (d) The pressure sensing sensitivity of NW-TENG sensor located in different pressure regions. (e) The reliability testing of NW-TENG device. (f) Charging curves for different capacitors (1 μF, 2 μF, and 5 μF).

good flexibility and can match well with human joints, generating various synchronized output signals during joint movement. Based on results in Fig. 5(b), the NW-TENG worn on the knee can generate sensing signals when the knee is bent, and as the bending angle increases, the peak value of the sensing signal also increases. In badminton, the position and state of fingers are also important indicators. Based on this, NW-TENG worn on finger joints can generate different voltage signals in different bending states of the fingers (Fig. 5(c)). The greater the degree of bending, the higher the voltage signal generated by NW-TENG. In badminton, wrist shaking is often used to hit the ball, and it is necessary to use NW-TENG to monitor the degree of wrist shaking (Fig. 5(d)). Determine the strength of a badminton player's wrist based on the peak value of the output voltage signal. Moreover, the NW-TENG installed inside the elbow can also monitor the swing amplitude of the elbow through voltage signals. Similar to the monitoring effect of other parts, the greater the amplitude of elbow swing, the higher the electrical output of NW-TENG (Fig. 5(e)). To measure the reliability of attitude sensing, we measured the average value of NW-TENG installed on knee, finger, and elbow after 50 consecutive operations and plotted a trend curve. The experimental results in Fig. 5(f–h) indicate that NW-TENG has good sensing stability.

4. Conclusions

In summary, a NW-TENG based on non-woven fabric was proposed to harvest mechanical energy and monitor badminton. The non-woven fabric and polytetrafluoroethylene (PTFE) form the triboelectric pairs. The non-woven fabric play the role of positive triboelectric layer and the PTFE film serves as the negative triboelectric layer. The aluminum foil is used for conductive electrode. NW-TENG exhibits a high service life and its output performance remains unchanged even after 5000 consecutive operations. The pressure sensing sensitivity of NW-TENG sensor can reach 1.22 V N^{-1} (Pressure range: 0–7 N) and 0.18 V N^{-1} (Pressure range: 8 N–55 N). Moreover, the NW-TENG can be installed on the body joints of badminton players for analyzing joint movements, thereby achieving data-driven badminton training and facilitating the evaluation of training effectiveness.

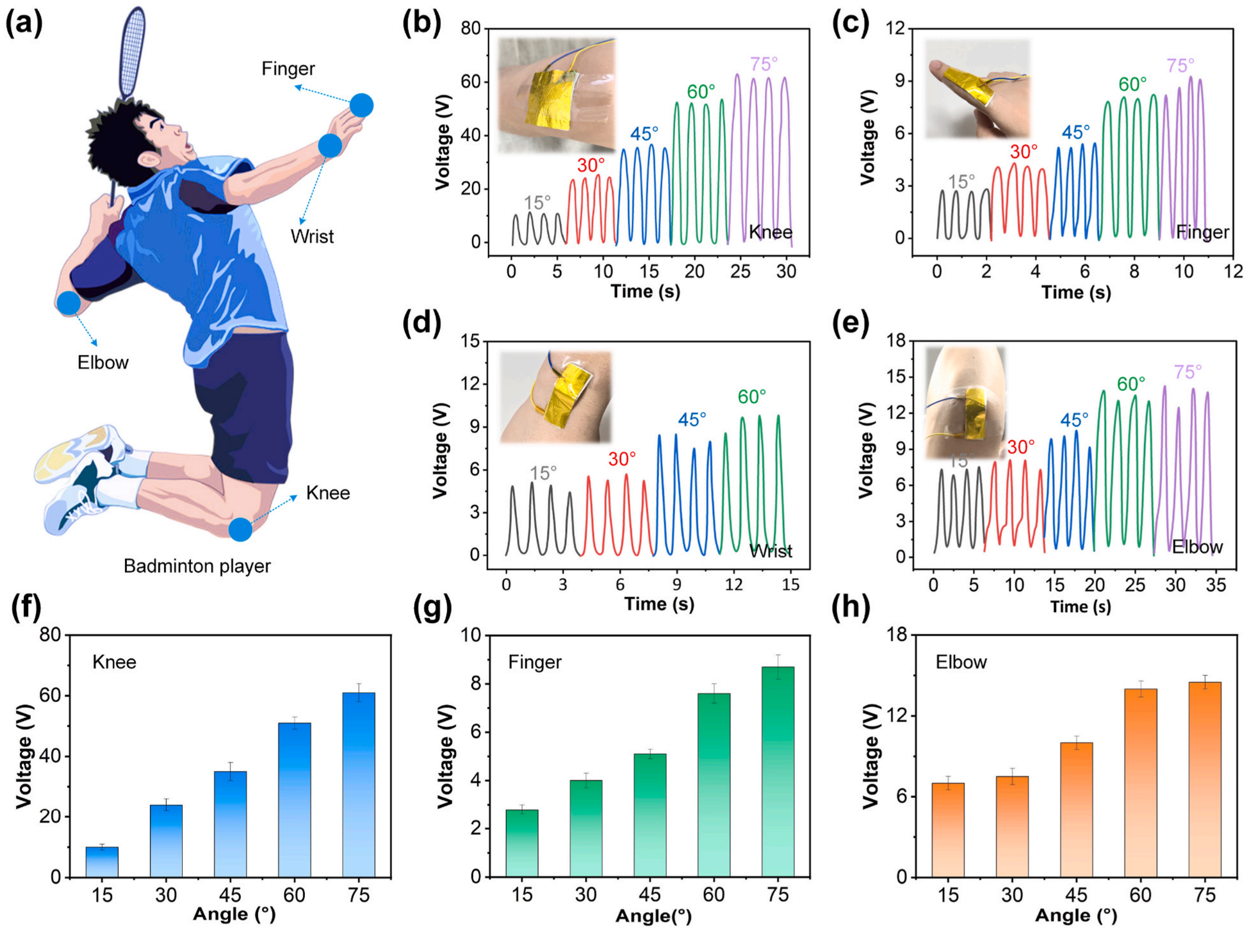

Fig. 5. (a) The cartoon picture of badminton player. The output voltage signal of NW-TENG installed on the (b) knee, (c) finger, (d) wrist, and (e) elbow. (f–g) The trend of average values from 50 experiments for output voltage signal of NW-TENG installed on the knee, finger, and elbow.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Min Wu: Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Zheng Li:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation.

Declaration of competing interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article, the manuscript entitled "A wearable flexible triboelectric nanogenerator for bio-mechanical energy harvesting and badminton monitoring".

Acknowledgements

This work was supported by the Provincial Education Science 14th Five Year Plan Project (JG21DB078), 2021 Scientific Research Project of Liaoning Provincial Department of Education (LJKR0269), 2022 Dalian Ocean University Education and Teaching Reform Project (202218), 2023 Scientific Research Project of Liaoning Provincial Department of Education (202302).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30845.

References

[1] N. Wen, L. Zhang, D. Jiang, et al., Emerging flexible sensors based on nanomaterials: recent status and applications, J. Mater. Chem. A 8 (48) (2020) 25499–25527.
[2] C. Zhao, Y. Wang, G. Tang, et al., Ionic flexible sensors: mechanisms, materials, structures, and applications, Adv. Funct. Mater. 32 (17) (2022) 2110417.
[3] Z. Chen, X. Chen, Y. Ma, et al., Human posture tracking with flexible sensors for motion recognition, Comput. Animat. Virtual Worlds 32 (5) (2021) e1993.
[4] G. Shen, Recent advances of flexible sensors for biomedical applications, Prog. Nat. Sci.: Mater. Int. 31 (6) (2021) 872–882.
[5] Z. Lu, Y. Zhu, C. Jia, et al., A self-powered portable flexible sensor of monitoring speed skating techniques, Biosensors 11 (4) (2021) 108.
[6] W.D. Li, K. Ke, J. Jia, et al., Recent advances in multiresponsive flexible sensors towards E-skin: a delicate design for versatile sensing, Small 18 (7) (2022) 2103734.
[7] Y. Su, C. Ma, J. Chen, et al., Printable, highly sensitive flexible temperature sensors for human body temperature monitoring: a review, Nanoscale Res. Lett. 15 (2020) 1–34.
[8] X. Yue, R. Lu, Q. Yang, et al., Flexible wearable optical sensor based on optical microfiber Bragg grating, J. Lightwave Technol. 41 (6) (2022) 1858–1864.
[9] H. Jiang, L. Zheng, Z. Liu, et al., Two-dimensional materials: from mechanical properties to flexible mechanical sensors, InfoMat 2 (6) (2020) 1077–1094.
[10] M.A. Khan, J. Sun, B. Li, et al., Magnetic sensors-A review and recent technologies, Engineering Research Express 3 (2) (2021) 022005.
[11] T. Delipinar, A. Shafique, M.S. Gohar, et al., Fabrication and materials integration of flexible humidity sensors for emerging applications, ACS Omega 6 (13) (2021) 8744–8753.
[12] R. Kumar, N. Goel, M. Hojamberdiev, et al., Transition metal dichalcogenides-based flexible gas sensors, Sensor Actuator Phys. 303 (2020) 111875.
[13] J. Luo, W. Gao, Z.L. Wang, The triboelectric nanogenerator as an innovative technology toward intelligent sports, Adv. Mater. 33 (17) (2021) 2004178.
[14] G. Khandelwal, N.P.M.J. Raj, S.J. Kim, Triboelectric nanogenerator for healthcare and biomedical applications, Nano Today 33 (2020) 100882.
[15] Z. Zhao, L. Zhou, S. Li, et al., Selection rules of triboelectric materials for direct-current triboelectric nanogenerator, Nat. Commun. 12 (1) (2021) 4686.
[16] W.G. Kim, D.W. Kim, I.W. Tcho, et al., Triboelectric nanogenerator: structure, mechanism, and applications, ACS Nano 15 (1) (2021) 258–287.
[17] Y. Zou, J. Xu, K. Chen, et al., Advances in nanostructures for high-performance triboelectric nanogenerators, Advanced Materials Technologies 6 (3) (2021) 2000916.
[18] W. Liu, Z. Wang, C. Hu, Advanced designs for output improvement of triboelectric nanogenerator system, Mater. Today 45 (2021) 93–119.
[19] Y. Zhou, W. Deng, J. Xu, et al., Engineering materials at the nanoscale for triboelectric nanogenerators, Cell Reports Physical Science 1 (8) (2020).
[20] B. Cheng, Q. Xu, Y. Ding, et al., High performance temperature difference triboelectric nanogenerator, Nat. Commun. 12 (1) (2021) 4782.
[21] R. Zhang, H. Olin, Material choices for triboelectric nanogenerators: a critical review, EcoMat 2 (4) (2020) e12062.
[22] W. Wang, A. Yu, J. Zhai, et al., Recent progress of functional fiber and textile triboelectric nanogenerators: towards electricity power generation and intelligent sensing, Advanced Fiber Materials 3 (6) (2021) 394–412.
[23] R. Cheng, K. Dong, L. Liu, et al., Flame-retardant textile-based triboelectric nanogenerators for fire protection applications, ACS Nano 14 (11) (2020) 15853–15863.
[24] K. Dong, X. Peng, R. Cheng, et al., Smart textile triboelectric nanogenerators: prospective strategies for improving electricity output performance, Nanoenergy Advances 2 (1) (2022) 133–164.
[25] H. Wang, M. Han, Y. Song, et al., Design, manufacturing and applications of wearable triboelectric nanogenerators, Nano Energy 81 (2021) 105627.
[26] Y. Zou, V. Raveendran, J. Chen, Wearable triboelectric nanogenerators for biomechanical energy harvesting, Nano Energy 77 (2020) 105303.
[27] D.G. Dassanayaka, T.M. Alves, N.D. Wanasekara, et al., Recent progresses in wearable triboelectric nanogenerators, Adv. Funct. Mater. 32 (44) (2022) 2205438.
[28] D. Doganay, M.O. Cicek, M.B. Durukan, et al., Fabric based wearable triboelectric nanogenerators for human machine interface, Nano Energy 89 (2021) 106412.
[29] G.I. Dzhardimalieva, B.C. Yadav, I.E. Uflyand, et al., A review on the polymers with shape memory assisted self-healing properties for triboelectric nanogenerators, J. Mater. Res. 36 (2021) 1225–1240.

[30] D. Yang, Y. Ni, X. Kong, et al., Self-healing and elastic triboelectric nanogenerators for muscle motion monitoring and photothermal treatment, ACS Nano 15 (9) (2021) 14653–14661.
[31] Y. Long, Z. Wang, F. Xu, et al., Mechanically Ultra-Robust, elastic, conductive, and Multifunctional hybrid Hydrogel for a triboelectric nanogenerator and flexible/wearable sensor, Small 18 (47) (2022) 2203956.
[32] X. Liu, M. Zhang, Z. Yang, et al., Alternating current electroluminescent device powered by triboelectric nanogenerator with capacitively driven circuit strategy, Adv. Funct. Mater. 32 (7) (2022) 2106411.
[33] C. Li, Y. Zhu, F. Sun, et al., Research progress on triboelectric nanogenerator for sports applications, Energies 15 (16) (2022) 5807.
[34] F. Sun, Y. Zhu, C. Jia, et al., Advances in self-powered sports monitoring sensors based on triboelectric nanogenerators, J. Energy Chem. (2023).
[35] X. Li, Z.H. Lin, G. Cheng, et al., 3D fiber-based hybrid nanogenerator for energy harvesting and as a self-powered pressure sensor, ACS Nano 8 (10) (2014) 10674–10681.
[36] M.F. Lin, J. Xiong, J. Wang, et al., Core-shell nanofiber mats for tactile pressure sensor and nanogenerator applications, Nano Energy 44 (2018) 248–255.
[37] M. Lou, I. Abdalla, M. Zhu, et al., Hierarchically rough structured and self-powered pressure sensor textile for motion sensing and pulse monitoring, ACS Appl. Mater. Interfaces 12 (1) (2019) 1597–1605.