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ORIGINAL

The innovative technology of triboelectric nanogenerators for intelligent sports

La innovadora tecnología de los nanogeneradores triboeléctricos para el deporte inteligente

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ABSTRACT

Intelligent sports development in the recently emerged Internet-of-things era is especially dependent on the gathering and analysis of athletic big data based on widely dispersed sensor networks. Conventional sensors have drawbacks such a short lifespan and high maintenance costs, and they typically require a separate power source. Recently, independent sensing devices and mechanical energy harvesting have been made possible with the ability to transcend these limitations through the use of triboelectric nanogenerators, or TENGs. Most notably, TENGs can be made from the materials most commonly used in sports—wood, paper, textiles, and polymers. An overview of recent developments in TENG development for intelligent sports is provided. First, an explanation of TENG's operation and how it relates to sports big data is provided. The creation of wearable technology and smart sports facilities, as well as TENG- based sports sensing systems, is then emphasized. Finally, the remaining difficulties and untapped potential are also covered.

Key words: Triboelectric Nanogenerators; Sports Equipment; Collection Mediums and Sports Monitoring.

RESUMEN

El desarrollo del deporte inteligente en la era del Internet de las cosas, de reciente aparición, depende especialmente de la recopilación y el análisis de macrodatos atléticos basados en redes de sensores muy dispersas. Los sensores convencionales presentan inconvenientes como su corta vida útil y sus elevados costes de mantenimiento, y suelen requerir una fuente de alimentación independiente. Recientemente, los dispositivos de detección independientes y la captación de energía mecánica han permitido superar estas limitaciones mediante el uso de nanogeneradores triboeléctricos o TENG. Los TENG pueden fabricarse con los materiales más utilizados en el deporte: madera, papel, textiles y polímeros. A continuación se ofrece una visión general de los últimos avances en el desarrollo de TENG para deportes inteligentes. En primer lugar, se explica el funcionamiento de los TENG y su relación con los big data deportivos. A continuación, se hace hincapié en la creación de tecnología vestible e instalaciones deportivas inteligentes, así como en los sistemas de detección deportiva basados en TENG. Por último, se abordan las dificultades pendientes y el potencial sin explotar.

Palabras claves: Nanogeneradores Triboeléctricos; Equipamiento Deportivo; Medios de Captación y Monitorización Deportiva.

INTRODUCTION

The sports sector has undergone a transformative change in the past two decades as a result of the rapid advancement of big data, cloud computing, and the Internet-of-things (IoT). The integration of sports into the digital era is made possible by this.[1,2,3,4,5] The progress of intelligent sports relies heavily on the cornerstone and core components of effective data collecting and analysis. Utilizing distributed sensors is crucial for the real-time collection of data. A wide range of highly sensitive and functionally diverse sensing technologies have been documented in the field of intelligent sports. These include optical, capacitive, resistive, geomagnetic, chemical, and thermosensitive technologies. However, a common draw- back of these devices is their need on an external power source for operation. While advancements in technology have resulted in reduced power consumption for individual sensors, sports applications sometimes necessitate the employment of a substantial quantity of such devices. The system offers high efficiency and a wide range of material options for converting dispersed, low-frequency, and unpredictable mechanical Identify applicable funding agency here. If none, delete this. Energy into electrical power.[2,6,7,8] Furthermore, TENGs have the capability to operate autonomously without relying on an external power source, serving as self-sufficient sensors for motion, pressure, touch, or acceleration. By integrating signal processing and transmission modules, it is possible to provide power to individual acceleration, pressure, motion, or touch sensors, allowing them to function independently. Therefore, a wide range of TENG technology will provide interesting and varied options for applications in the field of intelligent sports, where dispersed monitoring devices should be used. Here, we focus on the latest advancements in TENG technology specifically for the field of smart sports. Initially, we elucidate the functioning of TENG and its correlation with the utilization of big data in the realm of sports.[9,10] Currently, there is a focus on developing intelligent sports sensing systems that utilize TENG technology. Figure 1 illustrates the configuration of the A self-powered smart system that relies on TENG. To begin with, the installation of TENGs in sports facilities enables the recording of diverse mechanical triggering signals that occur during physical exercise. TENGs can also be integrated into wearable devices to detect bodily physiological indications.[3,11,12,13,14,15] In the sports business, a wide range of intelligent devices that employ TENG technology can be interconnected to form a network.[16,17]

Triboelectric nanogenerator

The fundamental physics framework of TENG can be correlated with Maxwell's equations, and it functions based on the interplay between contact electrification and electro-static induction. Since its inception in 2012, four fundamental modes of the TENG have been proposed: the vertical contact- separation mode, the lateral sliding mode, the freestanding triboelectric-layer mode, and the single electrode mode.[18] We employ the contact-separation mode due to the similarity in their operational principles. Sports entail a multitude of mechanical movements, wherein wearable technology, sports facilities, and human bodies will all interact to generate tribo-electric charges. This might potentially create numerous opportunities for the application of TENG technology. The initial condition does not include the creation or induction of charge. An exhaustive assessment of the mechanisms, advantages, and limitations of these four technologies is required. The sports industry is well-suited for the utilization of TENG technology, primarily because of its low-frequency characteristics and its ability to function as self-powered sensors, which aligns with the mechanical activities involved in sports and the prevalent adoption of TENGs. Therefore, it is logical to develop tribo- electric nanogenerators (TENGs) that can achieve autonomous sensing and effective mechanical energy harvesting to meet the requirements of various athletic equipment.[5,6,19,20]

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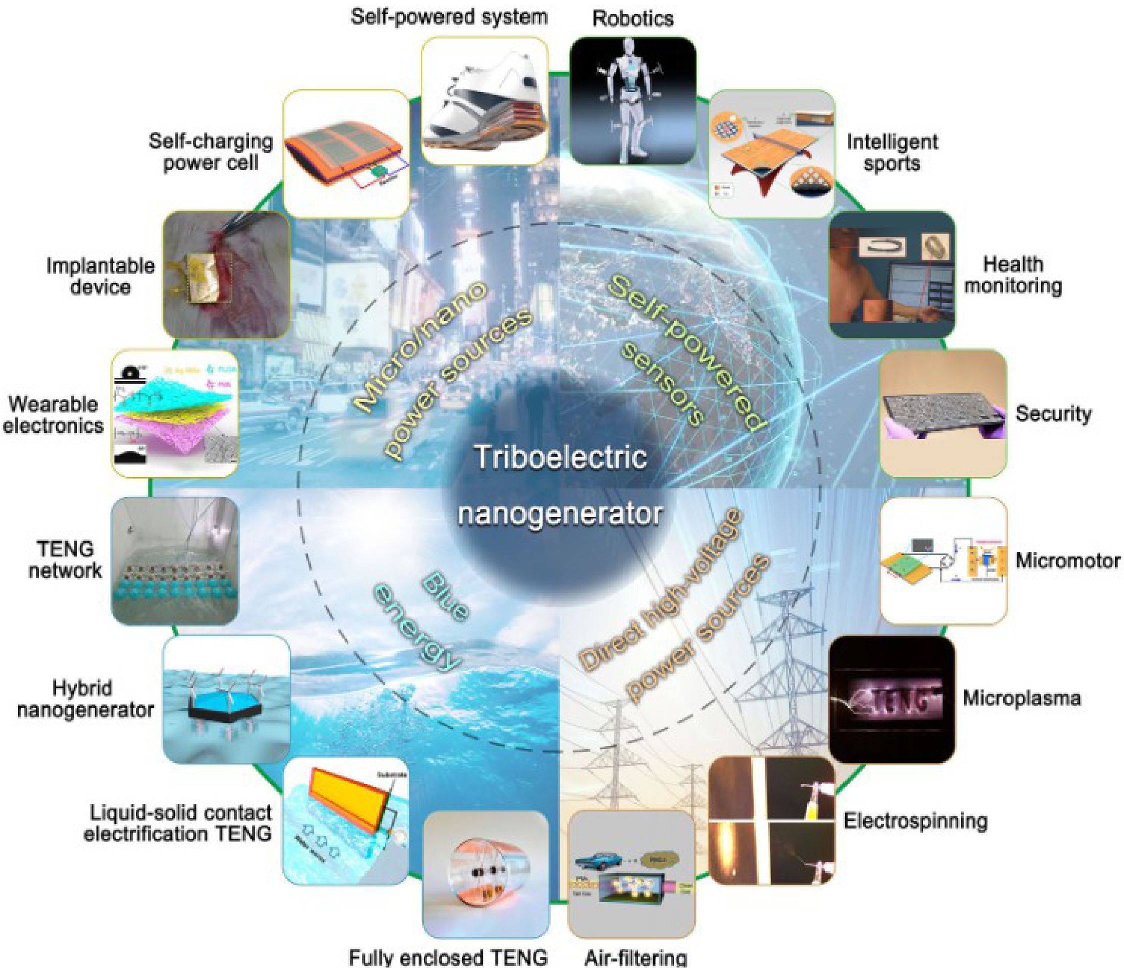

Figure 1. Direct high-voltage power sources, blue energy, active self-powered sensors, and micro/nano power sources are the four primary areas of use for TENGs

A. TENG-based Intelligent Sports

Triboelectric nanogenerators (TENGs) have the advantages of adjustable size, the capacity to work with various materials, and a user-friendly installation design. As a result, TENGs are an excellent method for capturing motion data in both indoor and outdoor athletic environments, including sports fields and equipment. To develop an intelligent ping-pong table, refer to figure 2a. Figure 2b illustrates the successful implementation of a self-powered falling point distribution statistical system. This system incorporates motion path tracking, distribution statistics, and velocity detection. These functionalities are obtained by positioning a TENG array on the surface. Athletes may utilize big data to accurately collect and analyze training data, which enables them to obtain scientific training evaluation and assistance. A self- sustaining edge ball assessment technology was also developed to expedite immediate referee judgments. When the ping-pong ball makes contact with the upper boundary of the table, the Top TENG device will provide a unique output signal. (figure 2c) The synchronous outputs of two TENGs can be compared numerically to accurately identify the two sorts of edge balls. Meng[18] developed a TENG (Triboelectric Nanogenerator) with a fully enclosed bearing construction, as shown in figure 2d. By attaching it to a bicycle wheel, one may instantaneously acquire numerous motion parameters of the bicycle, such as speed, acceleration, and distance traveled, by analyzing the electric signals produced throughout the ride. Figure 2e also described a cylindrical accelerometer with a translational-rotary triboelectric nanogenerator (TENG) that is self-powered. This device includes a power source and a rotational sensor to measure various parameters.[15,21,22,23] The structural diagram of the translational-rotary TENG is shown in figure 2f. To showcase the practicality of translational- rotary TENGs in intelligent sports applications, a sophisticated golf club was created to measure swing angle and hitting force (figure 2g). In addition, Peng et al. developed a separate surveillance system for boxing training and a robust, large-scale fabric-based triboelectric nanogenerator (TENG) (figure 2h).[24] In comparison to high-speed cameras, this system offers several advantages, such as cost-effectiveness and comprehensive data collection (containing metrics for punch strength, velocity, and quantity). In order to produce the self-counting skipping rope, Wang and his colleagues developed a yarn-based triboelectric nanogenerator (TENG) (figure 2i). Within A coherent exercise routine can be formulated by collecting sports data. Cao and colleagues devised a smart floor based on TENG technology, capable of monitoring and recording data during physical exercise. Several other investigations have endeavored to utilize Triboelectric Nanogenerators (TENGs) in the context of snow-related sports or intelligent combat. Athletes will experience enhanced performance as a result of utilizing these TENG-based intelligent sports facilities, which possess the capability to assess and quantify their actions across a range of sports equipment, as well as document their training sessions for the purpose of doing comprehensive data.[21]

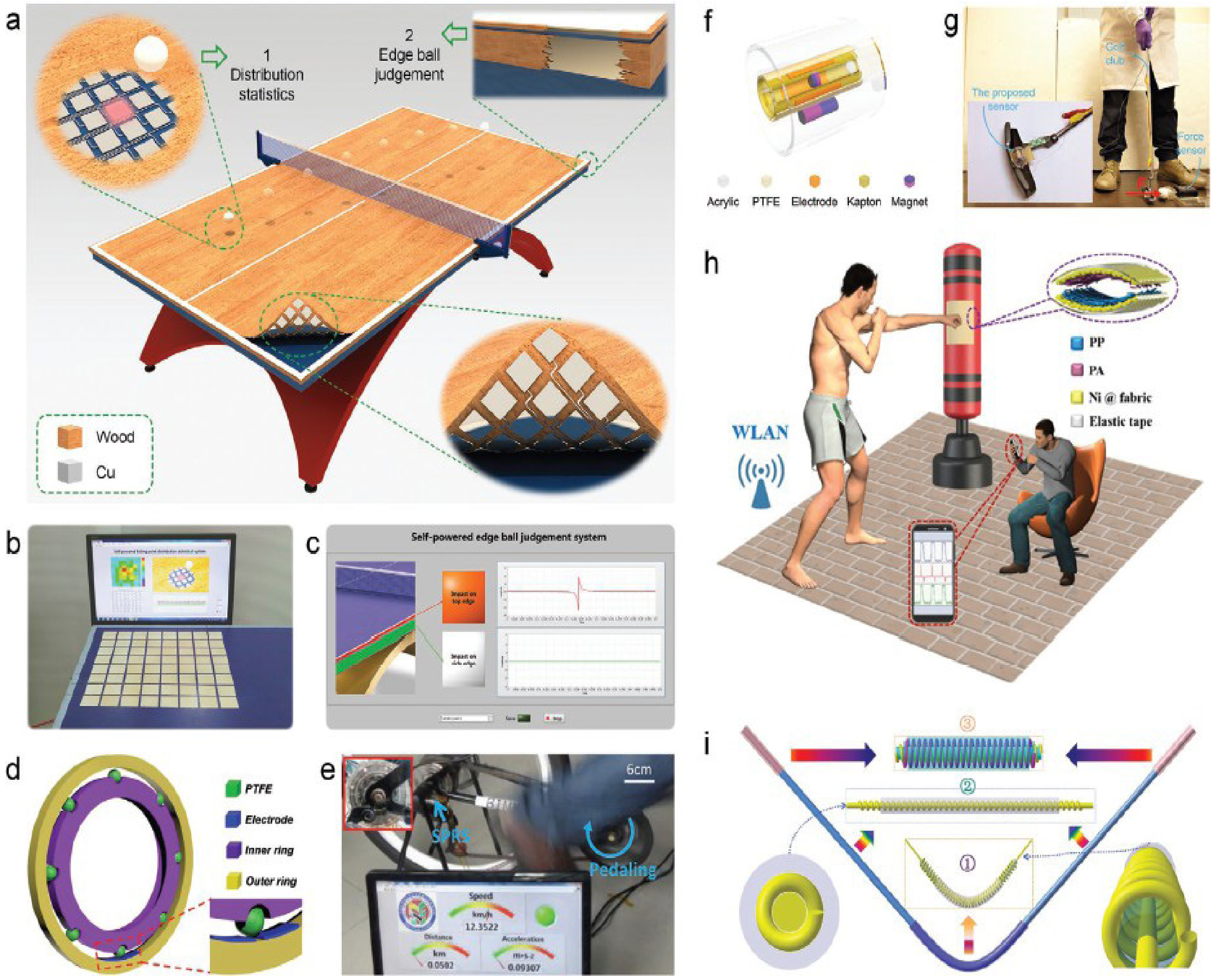

Figure 2. Illustrates the use of TENGs as sources of micro-and nanopower

A schematic design and photograph depicting the shape-adaptive Teng. B: The shape-adaptive TENG is depicted in the image. It has a pedal-like appearance and is positioned beneath the shoe. C: Images showcasing a configuration of 80 light-emitting diodes (LEDs) powered by the shape-adaptive tribo-electric nanogenerator (TENG) wristband. A–C, Authorized Reproduction. The number is 63. The organization is known as the American Association for the Advancement of Science. Copyrighted. Schematic diagram of a D, Symbiotic cardiac pacemaker system. The structural diagram of the implanted TENG is represented by E. The letters D and E are used with permission. Number 64 The publication is from Nature Publishing Group in the year 2019. Copyrighted. No reproduction or distribution without permission. The diagram illustrates the arrangement of the photovoltaic textile at the bottom and the TENG fabric at the top. G: The exhibition of the hybrid power textile's ability to generate electricity for small electrical gadgets. F and G are licensed reproductions. The number is 65. © 2016 Nature Publishing Group. All rights reserved. H-J, Modified utilizing Authorized for use. The number is 66. Copyrighted. No reproduction or distribution allowed without permission. Diagram illustrating the whirligig-inspired triboelectric nanogenerator (TENG). The proposed device is a self-powered glucose meter that utilizes a Triboelectric Nanogenerator (TENG) and draws inspiration from whirligigs. The letters K and L are used with permission. The number is 67. All rights reserved. copyright 2018. B.V.M. Elsevier Constructing a self-sustaining, dual triboelectric nanogenerator (TENG) electrocatalytic device for ammonia production. Authorized reproduction. The content is protected by copyright © 2020, RSC Publishing.

B. Wearable TENG-powered Systems

Wearable systems powered on TENG technology TENG is a highly effective energy harvesting technique that not only collects crucial signals from the human body to greatly enhance and facilitate our lives, but also has the ability to con-vert mechanical energy into electrical energy to supply power to all electronic devices.[20] Without interruption. To effectively address user requirements, it is crucial to consider the level of system integration, encompassing processes, configurations, and other factors. Additionally, maximizing the performance of TENG is essential to fulfill the power system's standard. Here, we introduce TENG-powered wearable systems, focusing on their process and performance levels. Figure 3A allows for continuous biosensing. The FTENG demonstrates a substantial power output of around 416mW m 2, which is sufficient for energizing multiplexed sweat biosensors and transmitting data wirelessly to user interfaces. The smooth integration of its system and good power management (PM) also enhance its performance. The FTENG-powered wearable sweat sensor system (FWS3) utilizes PTFE and copper as tribo-pairs to provide a strong electrification effect. Moreover, investigations of the transmitted charge densities of the FTENGs are employed to enhance the inter-electrode distance. Considering the potential of self-powered systems to adjust to the shape and position of the human body, figure 3B combines a gelatine-based triboelectric nanogenerator (TENG) with a non-invasive sensor on the insole and skin, respectively, to monitor the body's condition in real-time. The electric output of the TENG has the ability to regulate the density and dimensions of the energy needed for the electrochemical detection of the biosensor, as well as the electrocatalytic nanoparticles present on the sensing electrode. Furthermore, the wearable sensing device that was built demonstrates significant sensitivity and selectivity in detecting lactate. The TENG generates sufficient power within a minute of operation to analyze the quantity of lactate present in human sweat. Constructing the functional elements of the system based on the TENG model, and incorporating additional TENG units to gather and supply the necessary energy for wireless transmission and the system's processing circuits, is a more effective strategy. By employing this design methodology, the system's power consumption will be further reduced, ultimately achieving complete self-sufficiency. Figure 3C illustrates the integration of a Bluetooth module into a wireless body sensor network (BSN) system designed for heart-rate monitoring and wireless data transmission. The system includes a signal processing unit, a PM circuit, a heart-rate sensor based on TENG technology, and a downy- structure-based TENG (D-TENG). The D-TENG harnesses the kinetic energy generated by the motion of walking individuals to generate electricity. When operating at low frequencies, this device can generate a maximum power output of 2,28 milliwatts, achieving a total conversion efficiency of 57,9. It is capable of providing instantaneous and sustained power to the BSN system. In recent years, TENG-powered systems have experienced rapid growth in various industries.[10,25,26] These systems are characterized by their self-sufficiency, cost-effectiveness, non-invasiveness, and user-friendly nature. In addition to their participation in the aforementioned biomedical domains, TENGs have integrated into our daily existence. More and more wearable technologies will rely on TENGs, such as mobile bracelets that utilize embedded TENGs to activate liquid crystal displays (LCDs) or low-power digital displays by harnessing energy from the swing arm. P-TENG and the capacitive substance within the P-MSC. The electrical properties of many nanomaterials can degrade when subjected to deformations such as stretching. Figure 3D,E,F presents a SCPU (Stretchable Combed Carbon Nanotube) based on laterally combed CNT networks,[8] which aims to address these issues.[4] Enhanced conductivity and deformability are attained by employing additional designs for serpentine electrodes and applying nickel electroplating. The combination of these characteristics, together with the intrinsic electrochemical properties of CNTs, enables the development of highly efficient stretchable devices for harvesting and storing energy.[1] These devices include wireless charging coils, triboelectric nano-generators (TENGs), lithium-ion batteries (LIBs), and micro- supercapacitors (MSCs). A wearable SCPS is produced by integrating these devices in a monolithic manner, effectively showcasing its capabilities as an advanced soft power supply module for wearable technology. Wearable and portable smart devices need to address the issue of limited energy supply. One way to do this is by improving the compatibility between the SCPU and the device it powers. Further investigation is necessary regarding electronic gadgets and their associated circuit modules. Streamlining and optimizing the system configuration is an additional approach to improve system integration; this is further upon in the subsequent reference.[11] In general, several self-powered systems have utilized the triboelectric nanogenerator (TENG) as a power source to investigate its many uses for various purposes. Further information on these systems can be found in Further design is necessary to address the system's overall wearability and connectivity, the energy consumption of other modules, the energy transfer between modules, and the energy efficiency of TENGs. In addition, we need to find a compromise between the system's downsizing to enhance portability and the direct correlation between the output of TENG and its surface area.

C. Wearable Equipment

TENGs have the potential to be worn as gadgets that track the body's physiological signals. Fabric or silicone are examples of biocompatible materials that are used to create them.[27] In order to construct a wireless underwater system for tracking human movements, developed a bionic stretchy TENG.[25,26] They were successful because they mimicked the architecture of electric eel ion channels (figure 4a). The relationship between the arm's curvature and the voltage output of the Triboelectric Nanogenerator (TENG) is shown in figure 4b. As illustrated in figure 4c, athletes and swimmers alike can benefit from real-time motion signals by donning a set of four elastic TENGs on their knees and elbows. Figure 4d shows the textile-based triboelectric nanogenerator (TENG) array that Fan et al. shown can be smoothly integrated into different fabric regions for real-time physiological data monitoring. In figure 5e, we can see the all-textile TENG stitched into a cloth. A self-sustaining smart glove with haptic feedback was created by Lee and colleagues. Piezoelectric mechanical stimulators and triboelectric tactile sensors are built into the glove. The elastomer-based triboelectric palm sensor can simultaneously detect normal and shear pressures, as shown in figure 4f, which is an illustration of its architectural layout. A baseball game programme made use of the prototype glove to simulate hitting with haptic feedback and bat manipulation (figure 4g). They went on to use a self-powered super-hydrophobic triboelectric cloth to make a machine learning glove. Virtual and augmented reality (VR/AR) controls, such those for throwing a baseball or shooting a rifle, may now be implemented with great accuracy and in real time thanks to machine learning technology. The TENG is used to identify gestures, which are then used to conduct these controls. It is believed that these two pieces will increase the potential uses of TENG technology in virtual reality and augmented reality sports training. In addition to documenting the development of a biocompatible and flexible[22] TENG bandage, you and your colleagues have also succeeded in measuring muscle activity.[19] A rubber tube filled with physiological saline makes up the TENG band, as shown schematically in figure 4h. Images of the band in stretched and twisted states are shown in figure 4i, illustrating its outstanding quality. Deformability and malleability. Figure 4j shows that by attaching the TENG band to the arm or the leg, one may accurately collect quantitative data on motion, such as the distance travelled, the number of steps taken, and the velocity. A study on a smart insole that uses TENG technology to track many elements of walking was recently published by Lin et al. The two newly constructed triboelectric sensors are shown in figure 4k integrated into the front and back portions of the insole. On top of an elastic air chamber sits a TENG component in each sensor.

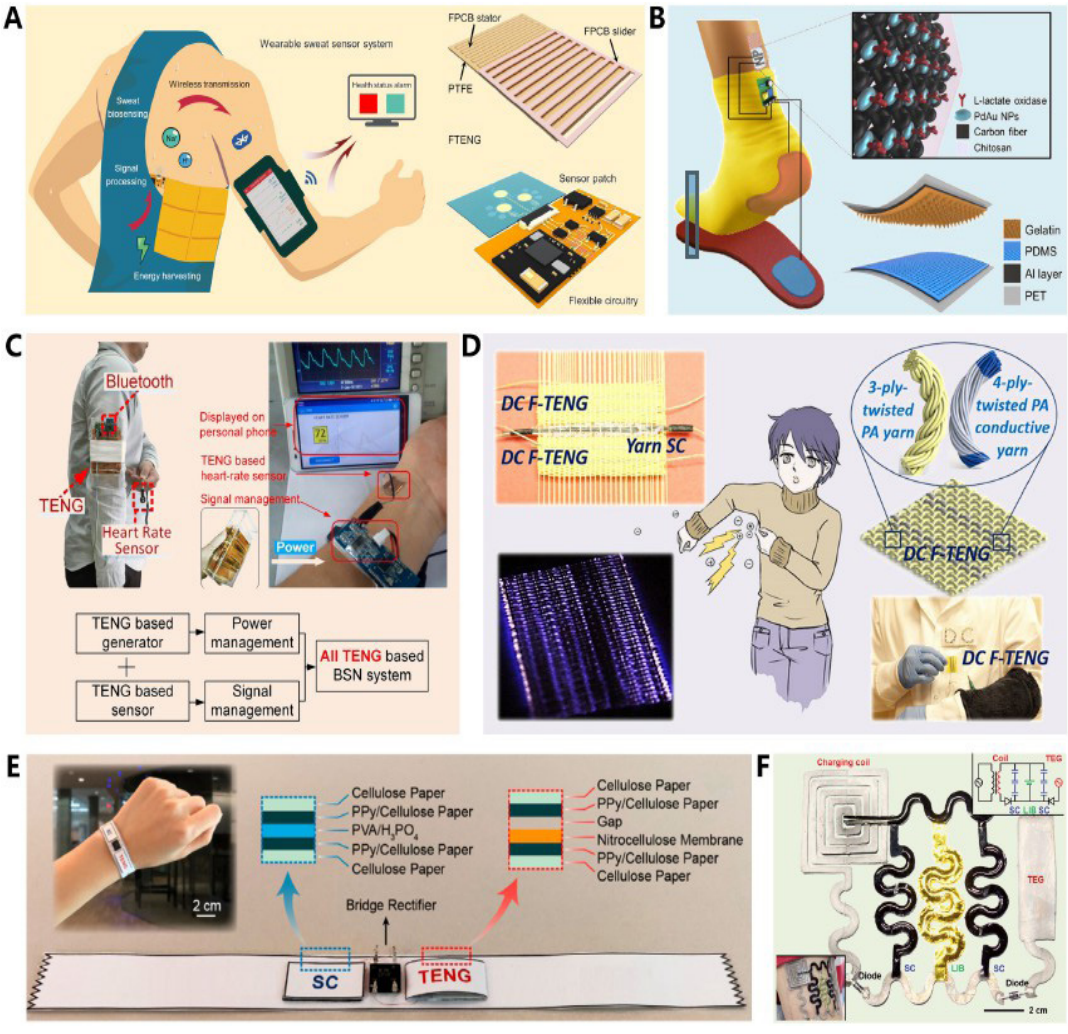

Figure 3. Displays wearable systems that are powered by Triboelectric Nano-generators (TENG)

(A–C) Performance-level integrations: (A) Molecular monitoring using the FWS3, which is wireless and non-invasive, and does not require a battery. Authorized for use. The authors, with copyright held by AAAS, released the work in 2020. (B) A wearable lactate sensor that operates without external power sources. Authorized for use. Elsevier (© 2017). (C) TENG facilitated heart-rate monitoring. Authorized for use. This content is protected by the American Chemical Society. All rights are reserved. (D–F) Process-level integrations: (D) The process involves the creation of a self-charging fabric by interlacing Yarn SC and DC F-TENGs.[12,13,14,28,29] Authorized for use. The organization is called the American Chemical Society. All rights reserved. © 2020. (E) A bracelet equipped with the ability to self- charge by utilizing paper. Authorized for use. The organization is called the American Chemical Society. Copyrighted. No reproduction or distribution allowed without permission. (F) A stretchy electrode-based energy supply system. Authorized for use. The publication was released by Wiley-VCH in 2017. All rights reserved.

An autonomous sock powered by a mix of piezoelectric and triboelectric mechanisms was created by Lee and colleagues (figure 4l). Through the integration of piezoelectric sensors and PEDOT: PSS-coated fabric TENG, the smart sock has the potential to accomplish numerous capabilities, including motion tracking, walking pattern recognition, and perspiration level monitoring. Furthermore, there is a plethora of reported wearable sports equipment based on TENG that targets certain areas of the body.[9] The smart home, healthcare, and sports industries will all feel the effects of the aforementioned TENG-based intelligent wearable gadgets.

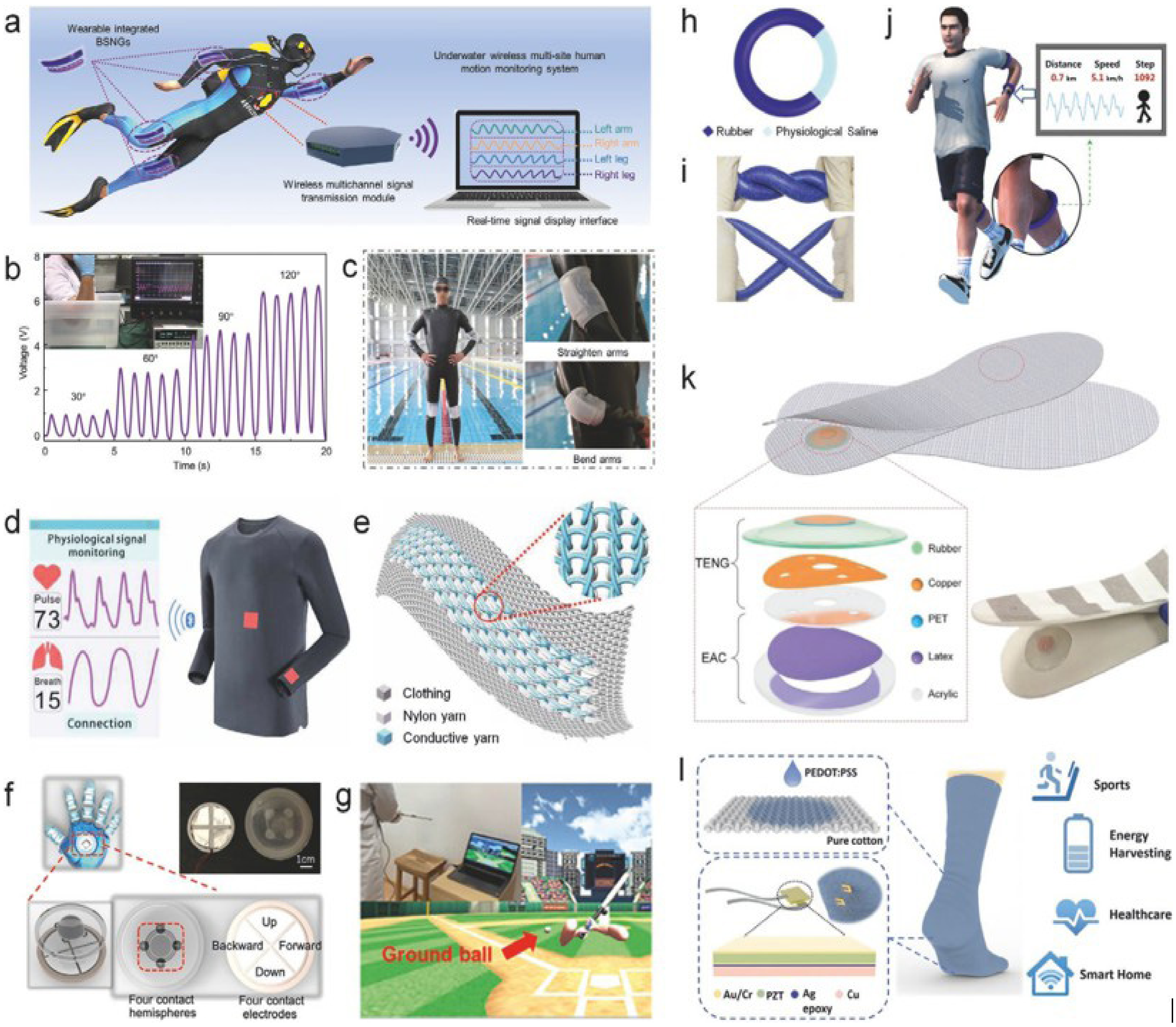

Figure 4. Wearable smart devices built using TENG framework

a) A bionic stretchable triboelectric nanogenerator (TENG)-based underwater wireless multi-site human motion monitoring system is depicted. b) The triboelectric nanogenerator (TENG) signal outputs when the elbow is bent at different angles during different motions. c) Pictures of bionic stretchable TENGs sewn into a patient's arthrosis for wearing use. from (a) to (c) reproduced with permission. As of 2019, the content is owned by Springer Nature and is protected by copyright. d) Live monitoring of respiration and pulse signals using two

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triboelectric nanogenerators (TENGs) built into a shirt. e) A schematic showing how vests can be equipped with triboelectric nanogenerator (TENG) technology. The TENG is shown in an enlarged perspective in the inset. Authorisation has been obtained to reproduce the content. The work of those affiliated with the American Association for the Advancement of Science is copyrighted in 2020. f) The haptic-feedback smart glove will use a triboelectric palm sensor, which has been constructed and photographed. g) Incorporating the augmented glove into a baseball gaming application. Authorisation has been obtained to reproduce the content. In 2020, AAAS will publish the information, which is protected by copyright. The writers who have some ownership over the material have given their consent for its reproduction or alteration from a reference. Copyrights to the material also belong to the sole licensee. The AAAS (National Academy of Sciences). You can get the schematic illustration of the TENG band at http://creativecommons.org/licenses/by-nc/4.0/. The illustration is distributed under a Creative Commons Attribution Non Commercial Licence 4.0 (CC BY- NC). the photos show the TENG band stretched out or twisted. j) A schematic of the TENG band, which allows for the exact tracking of quantitative motion data. Authorisation has been obtained to reproduce the content. The square brackets enclose the integer 53. This graphic provides a schematic representation of the TENG-based smart insole that can monitor gait. In 2019, Elsevier B.V. exercised its copyright on it. Reproduction with permission. The text entered by the user is "[54]". This work is protected by copyright held by Wiley-VCH and is valid until 2018. A smart cotton sock using a hybrid of triboelectric and piezoelectric technology is shown in the diagram. Reproduction with permission. Within the square brackets, you can see the number 55. The material is owned by the American Chemical Society and is subject to copyright protection. Copyright is in effect for the year 2019.

CONCLUSION

The sports industry is increasingly adopting digital and intellectual advancements, such as the use of wearable technology and smart sports facilities. Highly sensitive, durable, and low-maintenance sensors are essential for monitoring the extensively scattered sports data. Below is a concise overview of the latest advancements in TENG technology for the creation of autonomous smart sports facilities and wearable devices. TENG technology is expected to play a crucial role in advancing intelligent sports in the near future. Ensuring reliable and long-lasting performance: TENGs are susceptible to instability due to several external environmental conditions, including as humidity, temperature, and absorption, in practical scenarios.[23] The majority of sporting activities entail the continuous excretion of perspiration and salt, which has the potential to contaminate the TENG device. The progress of intelligent sports based on TENG will face a substantial challenge. Two highly effective methods to tackle this problem and enhance the hydrophobicity and self-cleaning capabilities of the triboelectric layers are the creation of surface nanostructures and the incorporation of hydrophobic chemical groups onto the surface. Another effective strategy involves the advancement of state-of-the-art packaging solutions that protect TENG devices from sweat infiltration without significantly impacting their electrical performance. Sensing accuracy: Currently, the development of TENG-based intelligent sports sensing systems has not given much attention to the accuracy of TENGs' sensing capabilities. Most researchers prioritize achieving sensing ability rather than enhancing accuracy. The rapid growth of the smart sports business will increasingly rely on the precision of sensor technology for successful commercialization. The electrical performance of TENG is directly linked to its sensing accuracy and can be improved by power management, structural design, and material alteration. Moreover, the precision of the sensing can be enhanced by employing the signal processing circuit. In order to implement a TENG-based sensing system in intelligent sports, it is essential to focus on miniaturization and modularization. These tasks are critical for the practical use of such a system. In the field of sports, it is imperative to enhance the TENG system by making it more small, lightweight, and efficient to ensure its practicality and comfort during use. It is crucial to take into account the stretchability, biocompatibility, breathability, and flexibility of TENG devices, especially when it comes to smart wearables. Additionally, the construction of a TENG-based wireless sensor network necessitates the assembly of many components, including the wireless transmitter, receiver, and data processing unit, to establish a highly modularized sensing system. To accomplish miniaturization and modularization of the TENG-based sensing system, it is necessary to focus on improving manufacturing techniques and enhancing output performance. An important concern and obstacle that must be addressed in the future is the optimization of Mini structures.

REFERENCES

1. Ren H, Yu S, Chao L, Xia Y, Sun Y, Zuo S, Li F, Niu T, Yang Y, Ju H, Li B. Efficient and stable Ruddlesden-Popper perovskite solar cell with tailored interlayer molecular interaction. Nature Photonics. 2020 Mar; 14(3): 154-163.

2. Zhang N, Huang F, Zhao S, Lv X, Zhou Y, Xiang S, Xu S, Li Y, Chen G, Tao C, Nie Y. Photo-rechargeable fabrics as sustainable and robust power sources for wearable bioelectronics. Matter. 2020 May 6; 2(5): 1260-

1269.

3. Wen DL, Deng HT, Liu X, Li GK, Zhang XR, Zhang XS. Wearable multi-sensing double-chain thermoelectric generator. Microsystems & nanoengineering. 2020 Sep 7; 6(1): 68. https://www.nature.com/articles/s41378-020-0179-6

4. Yang K, Cho K, Yang S, Park Y, Kim S. A laterally designed all-in-one energy device using a thermoelectric generator-coupled micro supercapacitor. Nano Energy. 2019 Jun 1; 60: 667-672.

5. Chen X, Guo H, Wu H, Chen H, Song Y, Su Z, Zhang H. Hybrid generator based on freestanding magnet as all-direction in-plane energy harvester and vibration sensor. Nano Energy. 2018 Jul 1; 49: 51-58.

6. http://www.nanotechbuzz.com

7. http://www.sciencemuseum.org.uk

8. http://www.prweb.com/

9. Sports Equipment: Global Industry Guide (2012), Mar-ketLine, Global Markets and Technologies for Carbon Nanotubes (2012), BCC Research Opportunities for Nanomaterials in Sporting Applications – 2008-2013: Trend, Forecast and Competitive Analysis, Research and Markets.

10. Patel V. Elastomeric Nanocomposites: Tyres spur Nanofillers market growth. Nanotech Insights. 2012; 3(4): 44-48.

11. Luo J, Fan FR, Jiang T, Wang Z, Tang W, Zhang C, Liu M, Cao G, Wang ZL. Integration of micro-supercapacitors with triboelectric nanogenerators for a flexible self-charging power unit. Nano Research. 2015 Dec; 8: 3934-3943.

12. Niu S, Wang X, Yi F, Zhou YS, Wang ZL. A universal self-charging system driven by random biomechanical energy for sustainable operation of mobile electronics. Nature communications. 2015 Dec 11; 6(1): 8975. https://www.nature.com/articles/ncomms9975

13. Zhang Q, Liang Q, Liao Q, Ma M, Gao F, Zhao X, Song Y, Song L, Xun X, Zhang Y. An amphiphobic hydraulic triboelectric nanogenerator for a self-cleaning and self-charging power system. Advanced Functional Materials. 2018 Aug; 28(35): 1803117. https://doi.org/10.1002/adfm.201803117

14. Luo J, Wang ZL. Recent advances in triboelectric nanogenerator based self-charging power systems. Energy Storage Materials. 2019 Dec 1; 23: 617-628.

15. Lin L, Xie Y, Wang S, Wu W, Niu S, Wen X, Wang ZL. Triboelectric active sensor array for self-powered static and dynamic pressure detection and tactile imaging. ACS nano. 2013 Sep 24; 7(9): 8266-8674.

16. Yin W, Xie Y, Long J, Zhao P, Chen J, Luo J, Wang X, Dong S. A self-power-transmission and non-contact-reception keyboard based on a novel resonant triboelectric nanogenerator (R-TENG). Nano Energy. 2018 Aug 1; 50: 16-24.

17. Jeon SB, Park SJ, Kim WG, Tcho IW, Jin IK, Han JK, Kim D, Choi YK. Self-powered wearable keyboard with fabric based triboelectric nanogenerator. Nano energy. 2018 Nov 1; 53: 596-603.

18. Meng B, Tang W, Too ZH, Zhang X, Han M, Liu W, Zhang H. A transparent single-friction-surface triboelectric generator and self-powered touch sensor. Energy & Environmental Science. 2013; 6(11): 3235-3240.

19. Fan FR, Tang W, Wang ZL. Flexible nanogenerators for energy harvesting and self-powered electronics. Advanced Materials. 2016 Jun; 28(22): 4283-4305.

20. J. Chen, Y. Huang, N. Zhang, H. Zou, R. Liu, C. Tao, X. Fan, Z.L. Wang, Micro-cable structured textile

for simultaneously harvesting solar and mechanical energy, Nat. Energy.2016; 1: 16138.

21. Yan C, Gao Y, Zhao S, Zhang S, Zhou Y, Deng W, Li Z, Jiang G, Jin L, Tian G, Yang T. A linear-to-rotary hybrid nanogenerator for high-performance wearable biomechanical energy harvesting. Nano Energy. 2020 Jan 1; 67: 104235. https://doi.org/10.1016/j.nanoen.2019.104235

22. Chen X, Song Y, Su Z, Chen H, Cheng X, Zhang J, Han M, Zhang H. Flexible fiber-based hybrid nanogenerator for biomechanical energy harvesting and physiological monitoring. Nano Energy. 2017 Aug 1; 38: 43-50.

23. Chen X, Ren Z, Guo H, Cheng X, Zhang H. Self-powered flexible and transparent smart patch for temperature sensing. Applied Physics Letters. 2020 Jan 27; 116(4): 043902. https://doi.org/10.1063/1.5134526

24. Wan J, Wang H, Miao L, Chen X, Song Y, Guo H, Xu C, Ren Z, Zhang H. A flexible hybridized electromagnetic-triboelectric nanogenerator and its application for 3D trajectory sensing. Nano Energy. 2020 Aug 1; 74: 104878. https://doi.org/10.1016/j.nanoen.2020.104878

25. Han WB, Lee JH, Shin JW, Hwang SW. Advanced materials and systems for biodegradable, transient electronics. Advanced Materials. 2020 Dec; 32(51): 2002211. https://doi.org/10.1002/adma.202002211

26. Li W, Liu Q, Zhang Y, Li CA, He Z, Choy WC, Low PJ, Sonar P, Kyaw AK. Biodegradable materials and green processing for green electronics. Advanced materials. 2020 Aug; 32(33): 2001591. https://doi.org/10.1002/adma.202001591

27. Sim K, Ershad F, Zhang Y, Yang P, Shim H, Rao Z, Lu Y, Thukral A, Elgalad A, Xi Y, Tian B. An epicardial bioelectronic patch made from soft rubbery materials and capable of spatiotemporal mapping of electrophysiological activity. Nature Electronics. 2020 Dec; 3(12): 775-784.

28. Poisel R, Malzer E, Tjoa S. Evidence and Cloud Computing: The Virtual Machine Introspection Approach. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 2013 Mar; 4(1): 135-152.

29. Gali M, Mahamkali A. A Distributed Deep Meta Learning based Task Offloading Framework for Smart City Internet of Things with Edge-Cloud Computing. Journal of Internet Services and Information Security, 2022 Nov; 12(4): 224-237.

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