WEARABLE TECHNOLOGY INNOVATION IN SPORTSWEAR

Wearable T

Disruptive Innova

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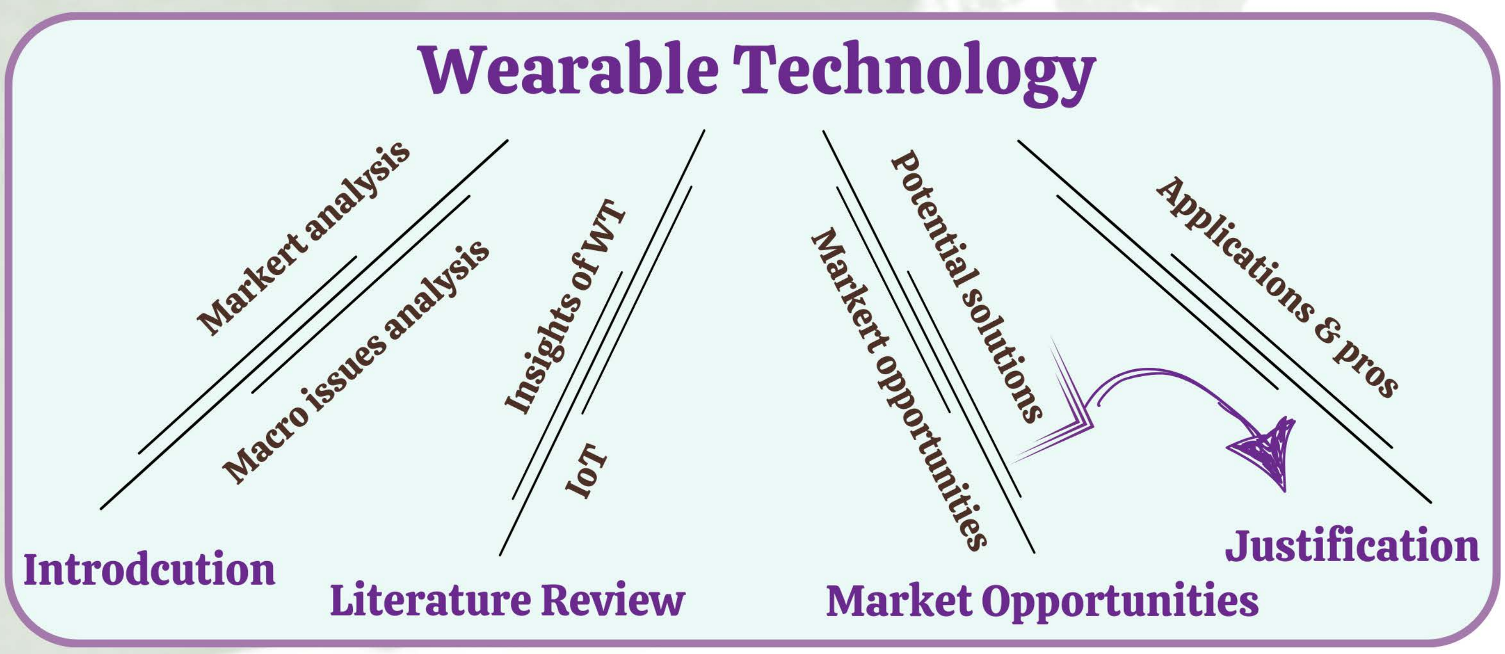
"The development of smart wearables and IoT is changing our lifestyles. Wearable technology will fully and permanently analyse, connect and support our bodies through smaller and more powerful devices, digital technologies and service-oriented product concepts."

Abstract

Wearable technology (WT) refers to electronic devices designed to be worn on the user's body. Such devices can take many different forms, including jewelry, accessories, medical devices, and clothing or elements of clothing.

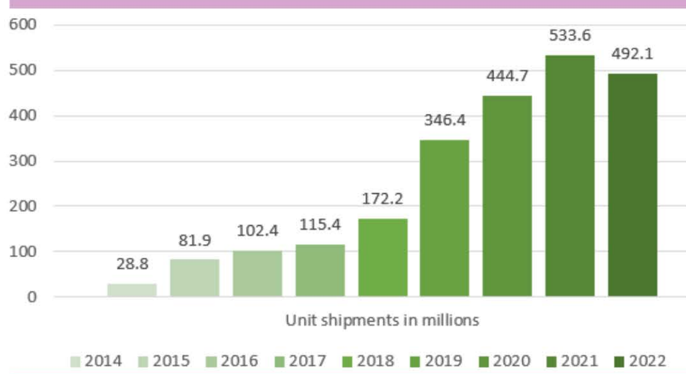
In this project, we analyse the macro issues of WT in sportswear and then explore the current applications and limitations of wearable technology in sportswear. Evenrtually, the following solutions are proposed: combining WT with **AI**, applying **nanotechnology** such as wearable nanogenerators, and employing **3D printing**. The above or other potential solutions are aimed at improving the **sports performance** of sports participants and improving the **sustainability** of smart clothing.

PROCESS MODEL FOR THIS PROJECT



Introduction

- Global shipments of wearable devices rea
- Global shipments of wearables **peaked** in
- Total global smart clothing market size rea
- Largest market of smart clothing is **North**
- Fastest growing area is **Asian-Pacific are** by **27.4%** form 2023 to 2030



SWOT and PESTEL analysis show the current ma technical level of smart clothing, including: **sustain materials, zero waste, manufacturing costs**

Market Opportunities

For the **Demand (Consumer)** Side

- Personal Health Monitoring
- Interactive & Social Connectivity
- Fit & Communication
- Performance Optimisation
- Environmental Adaptability
- Sustainable & Ethical Technologies

POTENTIAL SOLUTIONS

Integration of AI with Smart

By analysing the vast amounts of data generated by w personalised recommendations for improvement. On participants who want to access these services requir app, which can dramatically increase the brand's reve not only provide more detailed feedback on performa social platform to increase user engagement.

Nanotechnology

Nanotechnology help enhance the performance of sportsw waterproof, UV protection, self cleaning and thermal regul can contribute to the sustainability by reducing water con process, and creating biodegradable materials

-- Wearable Energy Harvesting & Stor

Wearable energy harvesting systems are powered by ener environment. Compared to conventional batteries, this sy comfortable, and provides a continuous supply of energy. powered sensors

Additive Printing/ 3D Printin

Compared to traditional textile technologies such as knitting it easier to create complex garments or even garments that a traditional technologies and with less waste in the productio complexity of the production process and the cost of materia smart garments. Furthermore, 3D printing allows for a high c expected to lead to massive customisation in the future.

Technology :
ation in Sportswear

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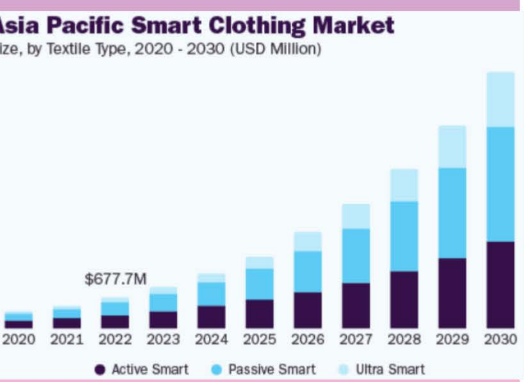
ched **492.1 million** units in 2022
2021
ached **$2.98 billion** in 2022
America
ea with CAGR expected to grow



acro-issues are mainly focused on the **nability, device performance,**

For the **Supply (Company)** Side

- Innovation in Product Development
- Market Differentiation
- New Revenue Stream
- Sustainability Leadership

Literature Review

CONSUMER SEGMENTATION

*For detailed UK consumers' attitudes, please refer to Chart 2.2 & 2.3

1. **Professional**

The primary users of sports wearable devices were initially elite athletes, who wore them to enhance performance and avoid injuries on the field.

2. **Amateur enthusiasts**

With the increasing awareness of fitness and health, sports wearable devices have gained widespread advocacy from health-conscious consumers who want to track their daily activities.

>75%

consumers expressed an openness towards future use of wearable devices.

82%

82% of consumers now consider health as a top or significant priority in their daily lives.

How to make the sportswear "Smart"?

SMART FABRICS 1

Also known as smart clothing and smart garments, which can be manufactured into smart vests, undergarments, smart shoes, smart socks, and smart tights. It can be defined as fabrics that can sense and react to the external environment via a pre-defined control mechanism or cognitive-driven behaviour.

2 SENSORS

lightweight sensors that can be embedded into flexible fabrics, including polyesters typically used in athletic wear, to constantly monitor vital signs, including body temperature, heart rate, and respiratory rate.

INTERNET OF THINGS (IOT) 3

WT, at its core, is **Internet of Things** devices and consist of three layers : **sensor, processing, and network**.

: Sensors

wearable sensors,providing
the other hand, sports
re a subscription to the brand's
enue. Additionally, the app can
ance, but can also be used as a

wear, such as windproof and
ilation.Moreover, nanotechnology
nsumption, improving the dyeing

rage

rgy from the human body or the
ystem is lighter and more
. They can also work as self-

ng

g and weaving, 3D printing makes
are impossible to produce with
on process. This reduces the
als used in the production of
degree of personalisation, which is

Justification

Integration of AI with Smart Sensors

→ **Additive Printing/ 3D Printing**: Optimising the 3D printing process by predicting and adapting material behaviour to create lighter, less material-intensive and more efficiently printed structures, helping to sense, adapt and predict the state of the printing environment to produce stronger and more reliable end products (Zhu, Ng et al. 2021). For sportswear, AI can help with design by analysing sports performance data

→ **Wearable Energy Harvesting and Storage**: Managing the distribution of harvested energy to ensure power is available when and where it is most needed and predicting the most efficient configuration and orientation based on environmental data and usage patterns significantly improves the efficiency of photovoltaic fabrics or piezoelectric elements in athletic apparel to ensure that the device has a reliable source of power from body movement or ambient light (Jia, Jiang et al. 2021)

AI can optimise energy generation patterns based on learning athlete movement habits to further optimise the placement and efficiency of energy harvesting materials in garments (Divya, Panda et al. 2023)

→ **Nanotechnology**: Artificial intelligence can analyse health indicators or environmental conditions monitored by nanosensors embedded in fabrics to adjust the fabric's properties. Examples include changing its permeability or insulation properties based on the wearer's body temperature or external weather conditions (Bishnoi, Rajaraman et al. 2021)

Predicting where and when damage is likely to occur during exercise and developing measures to reinforce these areas or control self-repair processes (Hui, Chan et al. 2007), ensuring that the material maintains its integrity and functionality over time.

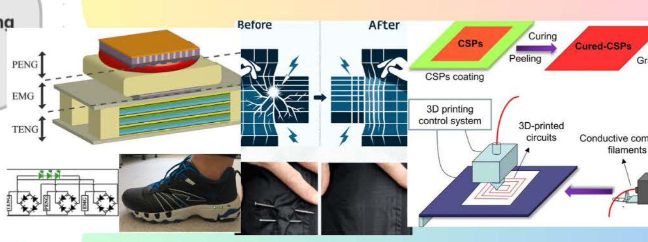
Nanotechnology

→ **Additive Printing/ 3D Printing**: The high surface area to volume ratios and short diffusion paths typical of nanomaterials provide solutions for achieving high energy and power densities simultaneously (Guo, Hu et al. 2008). In addition, the compatibility of nanomaterials with advanced manufacturing techniques (e.g., printing, coating, roll-to-roll assembly, etc.) allows for the design and realisation of wearable, flexible and foldable energy storage devices (Pomerantseva, Bonaccorso et al. 2019)

→ **Wearable Energy Harvesting and Storage**: Due to their inherently high surface area to volume ratio, nanomaterials have the advantage of fast charging and discharging cycles as well as higher power densities compared to their macroscale counterparts.

LIMITATIONS OF WT

1. Legal regulations regarding data privacy still need improvement
2. Lacking of accurate and reliable data
3. Potential interdisciplinary collaborations, including AI, 3D printing, and innovative sustainable materials.
4. Lacking of sustained user engagement:



CHALLENGES

- Data Privacy
- Trust in AI
- Performance of nanotechnoloy
- Material Limitation of 3D Printing

Advanced Textiles for Personal Thermal Management：The Principle and Innovation of Thermoregulating Ski Wear

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Introduction

Driven by consumer demand for high-tech solutions in healthcare and entertainment, the fashion industries are competing to create innovative smart garments.
This report provides an overview of the state of wearable thermoelectric materials and devices in wearable smart textiles, including **mechanisms, materials, manufacturing, device structures, and applications, as well as challenges and prospects.**

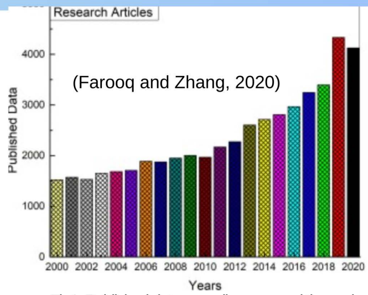
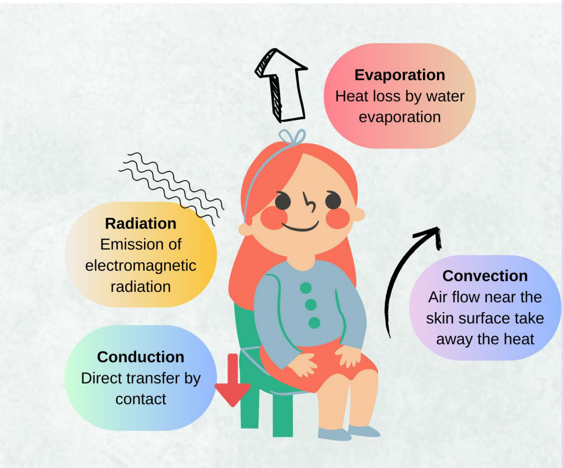


Fig1. Published data regarding personal thermal management from 2000 to June 20, 2020

Principle



Heat Dissipation Routes of the Human Body
(Authors own, 2024)

The human body generally dissipates heat via four routes: **radiation**, **conduction**, **convection**, and **evaporation**. Traditional fabrics capture air around the body, minimizing heat loss through convection and conduction but offers **little radiative insulation.** However, advancements in **energy innovation** and **nano-fabrication** technologies have made it possible to create advanced and adaptive materials for personal thermal regulation (Grodzinsky, 2020). By coating these fabrics with **silver nanowires (AgNWs)** to form a **metallic conductive network,** most human radiative heat can be reflected back to the body, significantly enhancing insulation level (Hsu et al., 2016).

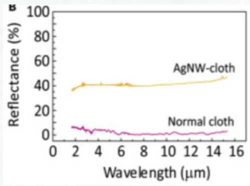


Fig2. Compared with normal cloth, AgNW-cloth obtains higher radiative reflection level.

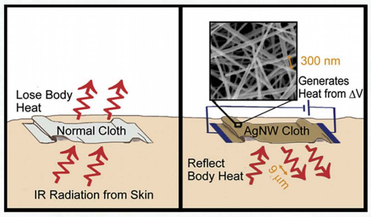


Fig 3. Concept illustration of Ag nanowire cloth with thermal radiation insulation and active warming (Peng and Cui, 2020)

How can outdoor apparel effectively regulate wearer's body temperature ?

- Passively conduction thermal insulation textiles
- Active heating textiles
- Integration with phase change materials

Challenges

1.Insufficient fit with the body in everyday wear.	**2. Substantial weight and limited capacity of batteries.**	**3. Stability concerns of sensors during physical activities.**
4. Restricted production scale and elevated costs.	**5. Issues with durability and washability.**	**6. Lack of standardized regulations**

Solution

This report presents a ski jacket model with responsive textile made with silver nanowires (AgNWs) that passively controls human heat dissipation routes, offers Joule-based active heating, and provides adaptive personal thermal management capabilities in response to external stimuli.

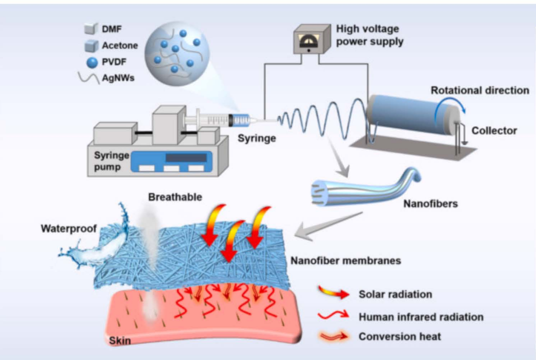


Fig. 1. Schematic diagram for preparing of PVDF/AgNWs nanofiber membrane. (Peng and Cui, 2020)

Key points

1.AgNW Conductive Network
1.1 High thermal insulation
1.2 Joule heating
1.3 Human infrared radiative reflection.
1.4 Light weight

2.Nanowires' porous structure
2.1 Breathability and durability.
2.2 Large interstitial spaces

3.Integration of Power Source
3.1 Thermal and electrical energy conversion (NewsRX, 2024)
3.2 Operates noiselessly
3.3 precise and reliable performance in wireless mode

Perspectives:

1. Seamless integration of devices and electronics
2. Advanced applications in big data and cloud computing a for intelligent data analysis.
3. New technologies in virtual reality and the Internet of Things (IoT).
4. Adhere to sustainability and biodegradability standards.

Rreference

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Wearable Triboelectrical Nanogenerators: Wearable Power Sources towards the Smart Sports and Sustainability

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Introduction

Wearable clothing systems are rapidly evolving and have been widely used in healthcare and sports. However, the issues of traditional battery storage limit their range of use (Fig 1). Thus, **wearable power sources** which can harvest energy from human activities or **self-powered sensors** based on **triboelectrical nanogenerators (TENGs)** are proposed as a possible solution

TENG combines the coupling effects of contact electrification and electrostatic induction to convert **distributed**, **irregular** and **low frequency mechanical energy** into **electrical energy**, including four basic modes that work in a similar process (Fig 2).

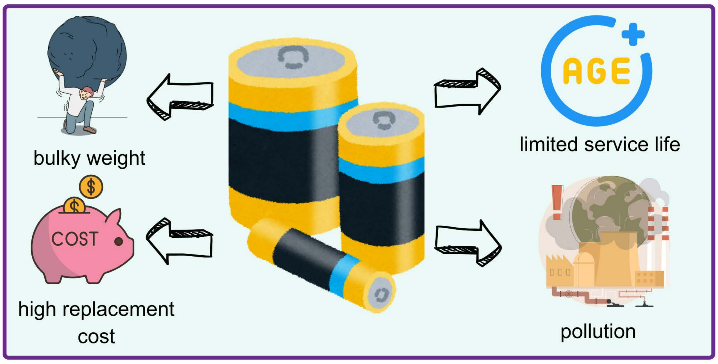


Fig. 1. Limitations of traditional battery storage

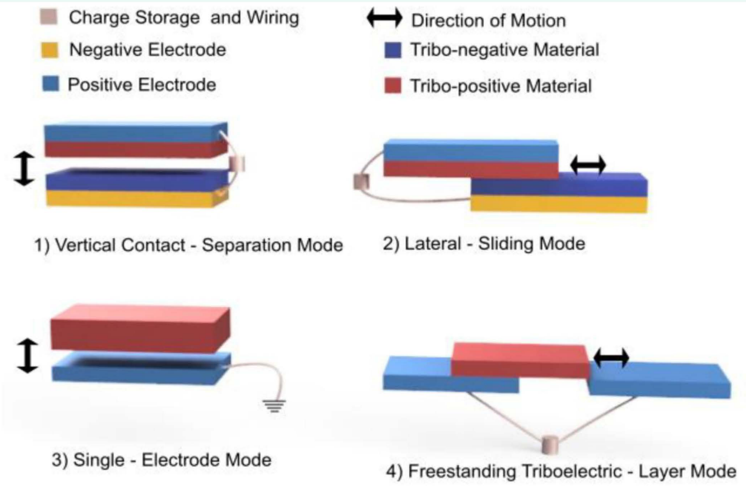


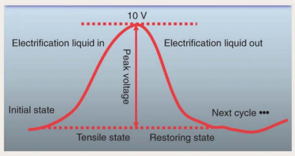
Fig. 2. Four basic TENG operation modes

Applications

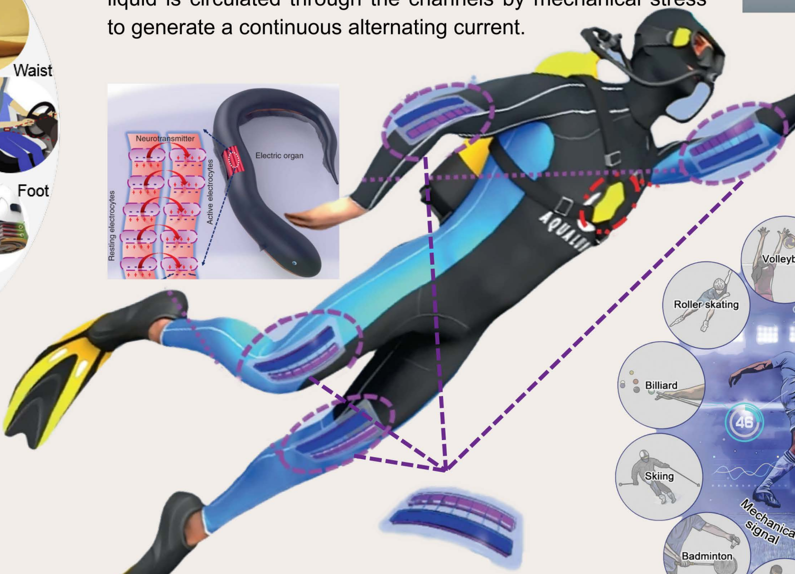
TENGs harvesting energy from various parts of human body

The biomechanical movements of different body parts have their own features and contain from a few watts to tens of watts of accessible energy.

Zou et al. (2019) proposed a stretchable TENG for underwater energy harvesting and sensing. Inspired by electric eels, mechanical control channels were fabricated by the stress mismatch effect between PDMS and silicone. Electrification liquid is circulated through the channels by mechanical stress to generate a continuous alternating current.

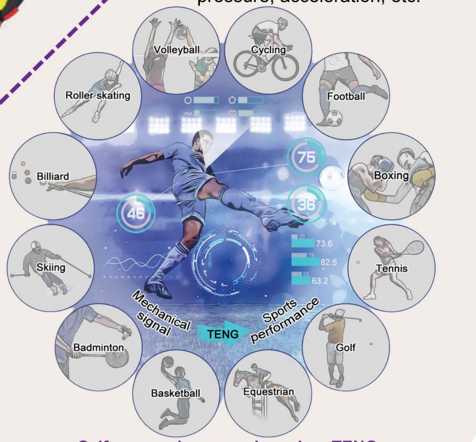


Output signal in one working cycle



Bionic stretchable TENG

Electrical signals obtained by TENG can also be used to sense mechanical stimuli such as tactile, pressure, acceleration, etc.



Self-powered sensors based on TENGs

Fig. 3. Applications of TENGs

Challenges & Perspectives

- Boost output power
- Improve wearability and washability
- Enhance mechanical durability
- Increase sensing accuracy
- Lower cost of materials and fabrication
- Package with high resistance to temperature variation, mechanical abrasion and sweat

Conclusion

Considering the **low-frequency** nature of most mechanical movements in sports, TENGs, which are made from flexible, stretchable and biocompatible materials, can be used widely in sportswear to help sports participants improve their **performance** and ensure **sustainability**.

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A new generation of customised insoles: smart insoles revolutionise sports performance

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Introduction

Improving sports performance and avoiding injuries are the biggest demands of athletes and everyday sports enthusiasts, and traditional sports shoes mainly focus on protection and basic support, lacking active performance enhancement and precise biomechanical feedback. As a result, there is a lack of smart insoles on the market that can keep up with the times to cope with the increasingly demanding market (Fig. 1).

With real-time data collection and analysis directly from the athlete's footwear, the new generation of smart insoles offer a new way of thinking for those with sports enhancement needs through pressure sensors, inertial measurement units, AI processor assistance, and antimicrobial 3D printed customisation technology. Suitable for a variety of lifestyle scenarios such as basketball, football, golf, running, hurdling and other sports. The insoles provide detailed insights into the foot's contact patterns, balance and strength distribution, enabling personalised adjustments and targeted training strategies. By integrating adaptive technology directly into the foot, smart insoles not only improve athletic performance, but also prevent injuries and promote recovery through customised support and feedback(Aroganam, Manivannan et al. 2019).

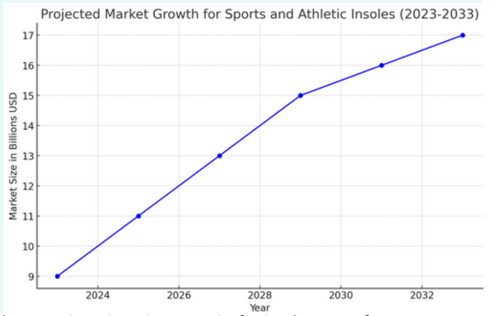

Fig. 1 . Projected Market Growth of Athletic Insoles from 2023 to 2033 (Author own)

Application Principles

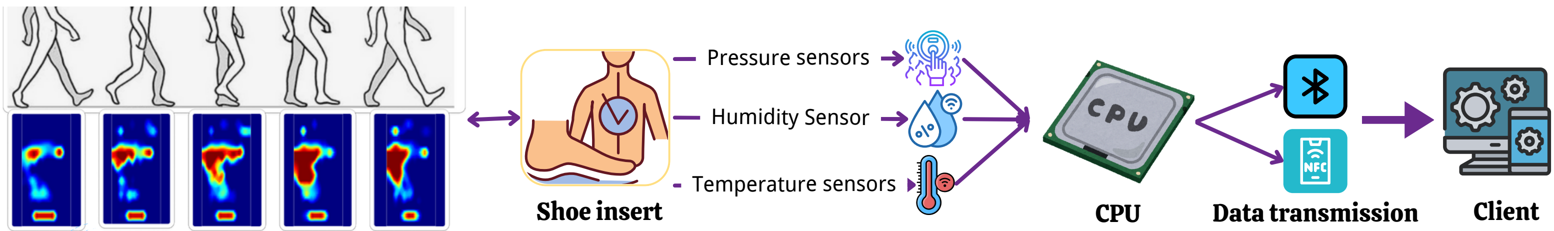

Fig. 2 .Visualisation results (Author's own)

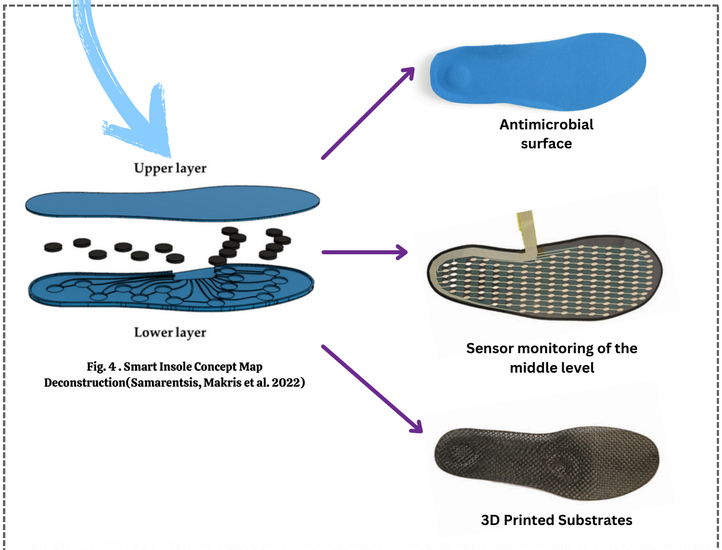

Fig. 4 . Smart Insole Concept Map Deconstruction(Samarentsis, Makris et al. 2022)

Sensor Layer Basic Functions

IMU Sensors: These sensors track three-dimensional motion and orientation, providing data on acceleration, rotation, and the force of gravity acting on the athlete's foot.

Pressure Sensors: Strategically placed throughout the insole, these sensors measure the pressure exerted by the foot at various points, providing insight into the distribution of loads and potential areas of pressure that could lead to injury(Refai, van Beijnum et al. 2018). (Fig. 2)

Temperature and Humidity Sensors: These sensors monitor the microclimate inside the shoe, providing data that can be used to assess comfort and the risk of conditions conducive to bacterial growth, which can affect foot health.

Friction Nanogenerators (TENG): Integrated TENG utilises the energy generated by the frictional interaction between the foot and the insole during movement. This innovative approach provides a self-sustaining power source for sensors, eliminating the need for batteries and enhancing the environmental friendliness and usability of insoles(Lama, Yau et al. 2021). (Fig. 3)

Limitations

Integration Complexity

Data Management and Privacy Protection

Durability and Reliability of Sensors and TENGs

Potential link contamination from composites of electronic components

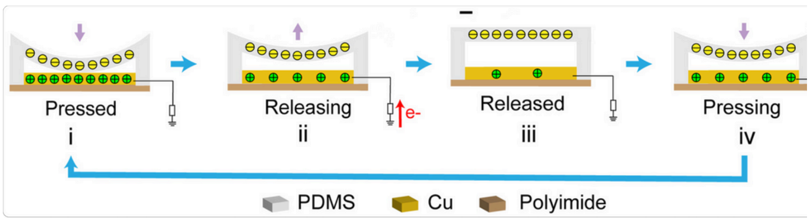

Fig. 3 . How TENGs work in insoles(Zheng, Dai et al. 2023)

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Improving body data monitoring accuracy during exercise with AI deep learning models

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Introduction

The use of smart wearable technology in the fashion industry is fast becoming a major area of research and development. From sports watches to smart clothing, these technologies are not only enhancing an individual's quality of life, they are also revolutionising the way we manage our health and track our body metrics. However, these technologies still face a number of key challenges at the present time.

-Monitoring data accuracy and reliability
-Wearing comfort of smart garments

Figure 1 Monitoring system for wearable technology(Aroganam, Manivannan and Harrison, 2019)

Solution

— With AI's **deep learning** ability and extremely strong **data processing capability**, the algorithm builds a 1D CNN model, which is able to significantly reduce errors
— While improving the accuracy of data monitoring, it **predicts** adverse conditions in the wearer's body and responds in a timely manner, reducing the occurrence of situations similar to sudden death in sports.
— During the manufacturing process of the garment, **lightweight** and **breathable** fabrics are used to enhance the wearing comfort of the smart garment.

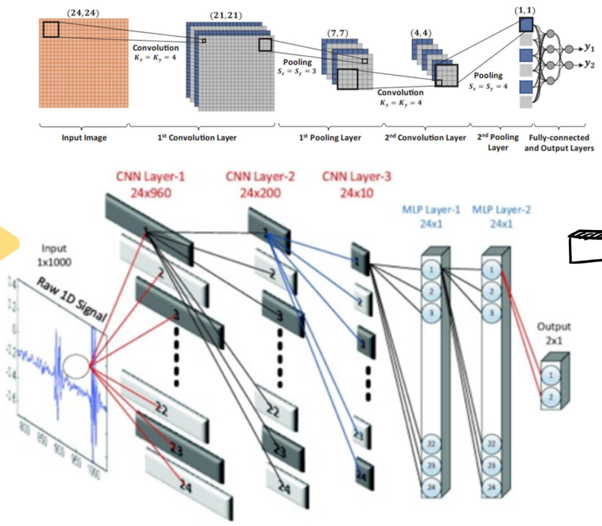
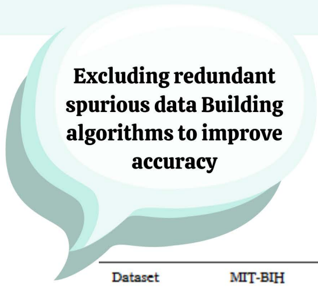
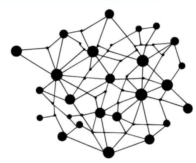


Fig. 2 Example of a simple 1D CNN configuration(Kiranyaz, 2021)





Dataset	MIT-BIH					
Classes	N	S	V	F	Q	Total Training Dataset
Number of heartbeats before SMOTE	72,741	2223	5778	641	6431	87,814
Number of heartbeats after SMOTE	72,741	72,741	72,741	72,741	72,741	363,705
Number of Testing Samples	21,892					

Fig. 3 Number of heartbeats before and after SMOTE application. (Velagapudi Swapna Sindhu et al., 2023)

Provides a more robust dataset with the help of Synthetic Minority Oversampling Technique (SMOTE) technology, which further improves the accuracy of data in predictive models

Conclusion

The 1D CNN, built with the help of a deep learning model of AI, can improve the quality of data by **pre-processing the collected data**, including **normalisation** and **denoising**, etc. This model is also applicable to other physical data detection to improve the accuracy and reliability of monitoring data during exercise.

Limitations

1. technical complexity and cost
2. Battery life
3. data privacy and security

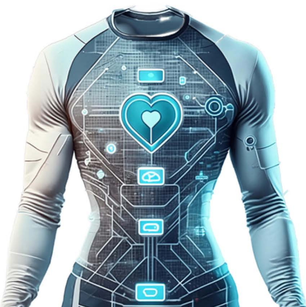


Figure 4. Conceptual drawings of the finished garments(Author own,2024)

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