Research and sustainable design of wearable sensor for clothing based on body area network

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Abstract
The body area network (BAN) is composed of every wearable device network on the body to share information and data, which is applied in medical and health, especially in the direction of intelligent clothing. A wearable device is an integrated body of multi-sensor fusion. At the same time, the multi-dimensional needs of users and the unique problems of sensors appear. How to solve the problems of wearable sensors and sustainable design is the research focus. Based on the wearable sensor in the critical factor of wearable device fusion, this paper analyses the classification, technology, and current situation of a wearable sensor, discusses the problems of a wearable sensor for BAN from the aspects of human–computer interaction experience, data accuracy, multiple interaction modes, and battery power supply, and summarizes the direction of multi-sensor fusion, compatible biosensor materials, and low power consumption and high sensitivity. The sustainable design direction of visibility design, identification of use scenarios, short-term human–computer interaction, interaction process reduction, and integration invisibility are introduced. The integration research of wearable sensors is the future trend, and it has been widely used in medical and health, intelligent clothing, wireless communication, military, automobile, and other fields.

1 | INTRODUCTION

The wearable device is an electronic product that can respond to the external environment and human need changes. Several wearable sensors integrate it with different characteristics. It is different in function, principle, and shape and is widely used in various social life fields [1]. With the rapid development of artificial Intelligence Technology, body area network (BAN), 5G technology, and quantum technology, wearable devices also encounter corresponding limitations, which cannot meet users’ multi-dimensional needs. As a crucial part of the core of wearable devices: the sensor is the crucial point of the problem, how to solve it is the focus. As the core of many industry development restrictions in the future, the wearable sensor has been focused on by the state and high-tech enterprises, and a lot of human resources and material resources have been invested in tackling fundamental problems. According to the survey of the literature and information research centre of the Chinese Academy of Sciences, the patent of the wearable sensor is overgrowing. China and the United States’ annual application volume is almost parallel, and the technology field involved is mainly human-computer interaction. It has several directions, such as electronic digital processing, medical diagnosis, and fingerprint identification [2]. Simultaneously, the potential value of wearable sensors has been invested by many capital institutions, which injects energy into the sustainable research and development of sensors.

At present, many experts say that smart clothing is the next outlet of wearable devices. We believe that clothing, like the second skin of the human body, has inherent advantages in establishing BAN, physiological data monitoring, and health treatment. The data and treatment effect will be more accurate [3], making up for the deficiency of available wearable devices. Therefore, this study takes wearable sensor as the research object, analyse the relationship between wearable sensor and clothing, ban, expound the classification, technology, and market status of the wearable sensor, explain the problems of a wearable sensor, put forward corresponding solutions, and put
forward nine sustainable design directions of a wearable sensor for clothing in the future. This paper puts forward reasonable solutions and sustainable design direction from wearable sensors’ current situation for clothing.

2 | RESEARCH BACKGROUND

2.1 | Smart clothing

Smart clothing is a product system that realizes specific functions by combining body or body like function carriers (especially the clothing of flexible fabrics) [4, 5]. This is also the author’s definition after five years of research on smart clothing, which is a relatively advanced and accurate explanation in China.

Smart clothing originated from the functional military clothing researched by the Massachusetts Institute of technology for the U.S. Department of defense. Smart clothing’s real progress has entered an explosive growth period after 2015, including the growth of annual shipment and design cases. The new direction of the intelligent wearable market in the future belongs to smart clothing [6, 7]. Professor Shen Lei's Jiangnan University team is the first team to put forward the concept of clothing safety in China. At present, there are more than 100 schemes. The intelligent diabetic socks are used to monitor the ulceration of eight acupoints of the foot according to the foot of diabetic patients’ sole temperature, which can remind the foot condition of patients. The principle is that the flexible temperature sensor monitors the temperature, integrates it into the sock data collector, and transmits it to the hand through Bluetooth. On the plane, users can see the data of foot temperature change, and upload it to the medical centre, relatives and friends’ mobile phones, so as to achieve data sharing; Professor Li Jun’s team of Donghua University is committed to China’s first warm manikin system for cabin Aerospace clothing experiment, mainly including the research and development of comfort functional clothing, clothing products, material evaluation of all kinds of clothing; Tao Xiaoming of Hong Kong Polytechnic University We have developed an intelligent wearable monitoring system, between COVID-19, which can monitor the user's body temperature, heart rate, vital capacity, blood oxygen, and other functional indicators; Fengjia University team has developed an intelligent physiological monitoring clothing, which uses elastic fiber and conductive fiber combined with wireless transmission to measure the wearer’s respiratory rate change, monitor the physical condition and emotional changes, and timely remind the user to adjust the breathing methods and speed; many schools in China are studying smart clothing, and only the more in-depth research schools are listed above. At the same time, in order to better analyse the direction and focus of intelligent clothing research, the author analysed 614 articles in web science database by using Visualizing Scientific Landscape (VOS) viewer Bibliometrics software, as shown in Figure 1, the co-cited knowledge mapping analysis with smart clothing as

![Figure 1: Knowledge mapping analysis of key words related to smart clothing papers abroad](image-url)
the keywords were conducted from 1983 to 2020. The number was labelled as the keyword clustering analysis, and seven large clustering regions (bright colour and large font) were obtained. It can be seen that technology, model, data, material, and fibre are essential aspects of smart clothing research. At the same time, it can be seen that in the related research abroad, around smart clothing, the sensor technology, fiber materials, technology, temperature monitoring, and other directions with good prospects in the future have been intensely studied, which is an advantage in foreign countries.

In domestic research, there are more researches on smart clothing in universities, such as Donghua University, Jiangnan University, Hong Kong Polytechnic University, Tongji University, and Beijing Institute of fashion; among enterprises, there are about six enterprises with real R&D capabilities, such as Fengmi technology and Zhishang. Foreign universities have also carried out relevant research. The wise Bioengineering Research Institute of Harvard University has developed intelligent combat clothing for military soldiers, which uses a large number of ribbon, built-in low-power processor and flexible strain sensor network to imitate leg muscles and movements, so as to reduce the risk of soldiers' injury; MIT has developed intelligent emotion monitoring clothing, which can improve the resolution through the bracelet capture in the intelligent clothing. Rate of physiological waveform, measurement of exercise, heart rate, blood pressure etc., is combined with artificial intelligence technology, to judge the mood in the conversation is happy, sad, neutral; Georgia Institute of Technology developed an intelligent ring, which can distinguish the small movements in the era of finger movement, and can use the finger to switch the phone, time and other functions; Manchester University developed solid flexible super capacitor fabric. Through the screen printing technology, the conductive graphene oxide ink is directly printed on the fabric, with low cost, high service life and self power supply; the University of Nottingham lundt has developed 3D printing underwear, 3D printing stretch silicone shaping clothes and a series of lace-up underwear with flower patterns, which can perfectly match the users. Monash University, NUS, NTU, Milan Polytechnic University, and other schools to study abroad. At the same time, researchers also analyse the research direction of smart clothing abroad through other channels. Chinese Science Citation in Web science retrieval database is obtained using smart clothing as keyword database using the VOS viewer data analysis software from 1983 to 2020 (see Figure 2). The domestic research on smart clothing is currently relatively late focused on smart clothing, sensor network, intelligent materials, functional clothing, research progress, big data, and program evaluation. It is relatively broad, but most of them are still in the primary stage, and few products enter the consumer market. However, there are a lot of universities and enterprises studying smart clothing in China. At the same time, the author has cooperated with domestic famous clothing brands to develop smart clothing. The research on intelligent diabetes monitoring socks and intelligent children's autism clothing is relatively in-depth. Simultaneously [10, 11], with the

**Figure 2** Knowledge mapping analysis of keywords in smart clothing research in China
development of artificial intelligence, Internet of Things (IoT) technology, and 5G technology in China, the scope, number of schemes, and future potential are discussed will have a more significant advantage (Figure 3).

2.2  |  Body area network

BAN, also known as human wireless local area network (LAN), is a human-centred wireless communication network composed of multiple sensor nodes distributed on the surface and inside the human body to monitor physiological information and personal intelligent terminals. In 2012, the wireless network communication standard was formulated by the IEEE802.15.6 [12, 13]. BAN is mainly used in medical, military, cultural, and entertainment fields. In these fields, the most widely used is in the medical field. As the smallest network form in the IoT, the BAN measures the human body's physiological parameters, such as temperature, blood glucose, blood pressure, and electrocardiogram (ECG) signal. It completes the data acquisition, processing, and transmission through sensors and information communication technology, connecting with an intelligent terminal, or connecting with a remote server through Internet server docking to achieve mobile or telemedicine services for family members, themselves, and doctors to view and share [14–16]. If clothing and wearable devices are the second skin of the human body, BAN, as a carrier, can also be considered as the nervous system of the second skin [17, 18].

There are many sensors on the human body, but they all work independently without any interaction. The existence of BAN is that sensors can share and share data through LAN, to improve the effective utilization of data information.

The combination of BAN and smart clothing is the interactive integration of technology and science and technology aesthetics and the three directions of human–computer interaction between BAN and wearable sensors on human parameters, external environment, and other devices. In the future, it must be a miniaturized network domain and sensor.

2.3  |  Wearable devices

2.3.1  |  Wearable device history

The data can be sensed and transmitted through wearable devices [19, 20]. Wearable devices have three elements of the human-machine environment interaction relationship: physiological data monitoring, security positioning, entertainment interaction, and other functions that have entered many social application scenarios [21]. According to the quarterly tracking report of China’s wearable device market in the third quarter of 2020 [22, 23], in the third quarter of 2020, China’s wearable device market shipped nearly 33 million units year-on-year growth of 15.3%. Although the market consumption rate has slowed down after 2018 and the impact of 2020 COVID-19, the wearable device market still maintains a good sales volume.

As shown in Figure 4, MIT professor Thorpe Shannon invented the earliest wearable device in 1966, which increased the success rate of gambling by 44%. In 1975, Hamilton watch launched the pulsar calculator watch, which is regarded as the first year of wearable devices. At this time, wearable devices have the function and significance of human–computer interaction [24, 25]. The current wearable process is divided into three stages: IT-Information Technology, DT-Data Technology, and IT-Intelligence Technology, each stage also represents
different wearable forms, different functions, and different networks. 2013 is the real wearable year. Since Google glasses’ appearance, wearable devices have a leap in quality and have unique artificial intelligence attributes [26–28].

2.3.2 | Wearable sensor becomes the key factor of wearable device fusion

Wearable devices are portable accessories composed of sensors, an app, and the cloud. The most important one is the wearable sensor, which is the core component of wearable devices. In recent years, one of the critical factors for the wearable device market’s growth is wearable sensors. Wearable devices’ function and performance are inseparable from the support of wearable sensors’ core technologies [29].

Wearable device fusion integrates multiple sensors to obtain data, then use the algorithm to cross-reference multiple information sources, and finally create a data image [30]. It can provide users with meaningful content quickly and accurately. Wearable device integration has been more than 10 years, quickly giving smartphones, watches, bracelets, cars, and other terminals.

At present, users’ demand for wearable devices is no longer single, with multi-dimensional requirements and experience. At the same time, wearable devices put forward higher requirements for the development of sensors (e.g. flexible, micro, and power supply), so the integration and innovation of wearable devices is a trend that must be forward, which can give users all-round data and images (demand) [31]. As the core of wearable devices, wearable sensors’ development is the key to promote wearable integration. Wearable sensors are fused by accelerometers, gyroscopes, and other sensors to monitor the transmission data and upload them to the cloud server and other terminals. Sensor fusion promotes the integration of wearable devices naturally [32] and becomes a leap across sports fitness, medical health, and other terminals Key factors of wearable devices such as consumer entertainment.

In wearable devices, the battery power supply problem is the core factor. For the product’s accuracy and accuracy, the sensor fusion + algorithm plays a vital role, effectively alleviating the power supply problem [33]. As shown in Figure 5, the simulation toolbox provided by MathWorks is used to analyse and evaluate the real sensor architecture simultaneously, as shown in [34, 35]. Besides, there are multi-target tracker, sensor fusion filter, and motion and sensor models.

FIGURE 4 Wearable device history (drawn by the author)

FIGURE 5 Target tracking using 3D bounding box based on LIDAR point cloud generation [34,35] (From Sensor Fusion and Tracking Toolbox). LIDAR, light detection and ranging
There are other aspects of the future development direction of wearable device integration, such as multi-functional integration, sensor and display integration, wearable device and fabric integration, ergonomics, in-depth analysis of human characteristics, flexible and functional materials.

3 | WEARABLE SENSORS

3.1 | Wearable sensor classification

Mobile devices such as smart wristbands and smartwatches can thoroughly monitor physiological information depending on the devices’ sensors. The technological embodiment of wearable sensors determines the application scenarios of wearable devices. As shown in Figure 6, according to the characteristics of measurement parameters and functions, wearable sensors are divided into three directions: motion sensor, biological sensor, and environmental sensor. The sensor is widely used in smart bracelets and smartwatches and monitors sports physiological data and health information [36, 37].

At present, heart rate, blood oxygen, sweat, blood glucose, and body temperature are the main monitoring contents (physiological information). With the development of wearable technology and algorithms, the development trend of sensors is also changing. The heart rate sensor is supplemented with blood oxygen and other indicators to improve accuracy, and other essential sensors eliminate motion noise. The blood oxygen sensor continuously monitors blood oxygen, pulse, and other comprehensive indicators to improve the blood oxygen algorithm’s quality further. The sweat sensor uses micro-nano processing technology to identify subtle changes in sweat more accurately and shorten the response time; the blood glucose sensor gradually matures using spectral analysis technology. The temperature sensor tends to be miniaturized and flexible. The thermal response time is shortened and combined with heart rate, vital capacity, and other indicators [38]. In the future, enterprises’ development trend is to embed the flexible sensor into the physiological pad, which is similar to that of many enterprises.

3.2 | Wearable sensor technology

The wearable sensor includes hardware (communication hardware and data acquisition hardware), software (interactive sensing and software), and data analysis technology [39]. Wearable technology is an essential part of wearable sensors and an essential bridge between human and wearable devices. At present, the related wearable sensor technology has the following parts:

1. Biometric authentication technology. Biometric sensors use human body biomarkers for human–computer interaction and are widely used in mobile devices. The fingerprint authentication function in smartphones is to capture finger fingerprints for mobile phone unlocking and payment functions, and we have had in-depth experience. The pre-loaded mobile payment function bound by smartphones and bracelets can only complete the payment function using the bracelet (mobile sensing monitoring) even if you do not bring a mobile phone when you travel.

2. Mobile health monitoring technology. Mobile health monitoring technology includes physiological indicators such as body weight, BP, blood glucose, ECG, sleep, and skin electrical response. Wearable sensor technology uploads these data to the mobile app and cloud service data centre for monitoring, analysis, and feedback [40]. If wearable devices have medical authentication and user agreement, the collected data can also be sent to hospitals and community medical centres to monitor and improve patient care.

3. Energy acquisition technology. Energy collection technology is to obtain external energy to improve the application of wearable sensors and devices. Radio waves, temperature difference, solar energy, body kinetic energy, and mechanical vibration can be used as the sources of energy collection to provide power for mobile devices, which is also the trend of wearable devices to solve the power supply function in the future.

4. Adaptive electronic technology. It mainly refers to tracking and electronic component technology packaged in

| Sensor type       | Sensor                           | Application Equipment | Major Function                              |
|-------------------|----------------------------------|-----------------------|---------------------------------------------|
| Motion sensor     | Gyroscope, accelerometer, pressure sensor and magnetometer, etc | Bracelet, watch and other equipment | Motion monitoring, navigation and human computer interaction |
| Biosensor         | Blood glucose, blood pressure, ECG, body temperature, EEG and EMG sensors | Health care related equipment | Health and medical monitoring |
| Environmental Sensors | Temperature and humidity, environment, ultraviolet, particle, gas, pH, air pressure and microphone sensors | Bracelet, medical and other related equipment | Environmental monitoring, weather pre explosion and health alert |
flexible and elastic polymer materials. Nowadays, wearable components, such as biological skin patches, electronic skin, electronic tattoos, and intelligent clothing, are all provided with functions by using adaptive electronic technology. This technology can make various parts of the human body electronic skin components and achieve non-invasive monitoring data.

5. Accurate motion recognition technology. There are gyroscopes, accelerometers, magnetometers, and other motion sensors in wearable devices. Different types of actions are determined by sensor fusion algorithm [41–43]. Smartphones and watches have step counting function, which is all derived from action recognition technology. In the future, the algorithm's accuracy will be higher, and the error will be reduced to very small.

To understand the research direction of wearable sensor technology patents in recent years, the author obtained 1500 patents through the EU patent database centre. The search keywords are wearable sensor technology, and the time range is 2018–2019. At the same time, VOS viewer data measurement software is used to analyse the keywords. As shown in Figure 7, the keywords of wearable sensor technology patents are divided into four colour areas. Each colour area represents different hot spots. The green area mainly represents the wearable sensor power consumption and battery, battery equipment, energy, and battery management. The yellow area mainly represents the BAN, sensing and measuring (e.g. pressure, temperature, step, and action). The Blue area represents the wearable sensor technology patent hot keywords. The colour area mainly represents other equipment and technology, data integration, behaviour recognition, and deep learning. In addition, the red area mainly includes materials and biotechnology, blood detection, flexible methods, clinical and experimental. Generally speaking, wearable sensor technology patents' hot research directions mainly focus on body area networks, data integration, and sensing measurement, which is also a hot research direction and the author's research focus.

3.3 Market status of wearable sensors

As we have said before, China's wearable device shipment will reach 33 million units in the third quarter of 2020. It is not easy to achieve the growth trend even though the world will be seriously affected by COVID-19 in 2020. Figure 8 shows the shipment volume of China's wearable device market from 2015 to 2019. With the rapid development of China's IoT technology and artificial intelligence technology, the wearable device market will also increase from 75 million units in 2015 to 204 million in 2019. The overall market trend is a straight-line rise, indicating that China’s wearable device market is enormous and has tremendous domestic demand.
China has the largest population in the world. Simultaneously, with the growth of economic capacity and per capita GDP, the consumption power of Chinese people has changed from single function to multi-dimensional function consumption. There are many sensors inside the wearable devices, such as smartwatches, bracelets, headbands, and glasses. The distribution of China’s wearable sensor products is shown on the top three in terms of the proportion structure in Figures 9 and 10. The Chinese wearable sensor products are widely used in wearable devices, including pressure sensors, acceleration sensors, and image sensors. With the development of the IoT and artificial intelligence technology, biosensors, distance sensors, and image sensors will be further improved in the technology and consumer market in the future [44].

The consumer market is one of the essential indicators to consider product ability. At the same time, the emergence of more wearable sensors makes consumers put forward high requirements. The volume, function, quality, and stability of wearable sensors will affect consumers’ user experience, which needs sensor integration and innovation. At present, wearable devices have some problems, how to solve this problem is also the focus of the author’s research.

4 | PROBLEMS AND METHODS

Problems and solutions of wearable sensor for BAN.

4.1 | The relationship between BAN and wearable sensor

Before, we have explained the BAN. Here, what is the relationship between BAN and wearable sensor?

As we all know, in BAN, each sensor is a network node, which forms the whole BAN under the support of standard communication technology (central processing node) [45]. As shown in Figure 11, the relationship network between the sensor node and the central processing node is gathered in the central processing node by the communication technology of the sensors distributed in various parts of the human body to form the body area data of body monitoring. In Figure 11, only four sensors that are more important for body data monitoring are marked. The CPU node is composed of ZigBee/GPRS, which can realize the data exchange between them.

The human physiological data monitored by wearable sensors can share data and interact with each other through BAN to achieve data transmission efficiency and accuracy. Therefore, both of them are indispensable and interact with each other from the perspective of attribute relationship.

4.2 | Problems of wearable sensors for clothing

Every country is vigorously developing the wearable device industry, and the public health market industry has been paid
more attention, especially the research of medical wearable sensors. In 2004, the European Commission launched the world’s largest civil wearable computing research project. The National Science Foundation of the United States funded several wearable medical and health research projects. China launched the active elderly health project to fund wearable research projects in medicine and health. In addition, other countries are also participating. The research of wearable medical sensors is proposed.

The wearable sensor industry is in a period of rapid growth. Companies such as Epocrates, cardionet, welldoc, zocdoc, and vocera have made successful examples in the field of wearable medicine. However, the richness, data accuracy, and functionality of its products are still unable to meet the market demand, and the whole industry is still in the stage of rapid growth, which can be expected in the future.

As shown in Figure 12, the typical products sold by China’s wearable technology enterprises are mainly inpatient monitoring, health tracking, and intelligent physical examination. The marketing feedback is relatively good, such as Xiaomi’s health intelligent Sphygmomanometer, which can measure blood pressure with one touch through mobile phones and smart accessories; Ruiren temperature monitoring has the function of temperature monitoring and monitoring and can participate in temperature monitoring in real-time, especially during the period of COVID-19, which has a good effect. However, at the same time, consumers also find many problems, such as the lack of data accuracy, complex operation interface, and personal privacy that cannot be fully protected.

As shown in Figure 13, the products sold by foreign wearable enterprises are involved in sign monitoring,
prevention, and treatment of chronic diseases. It can be seen that the research on wearable in foreign countries is relatively early, and it can be further studied in the field of medical and health. There is still much distance between China and foreign countries. The product orientation is relatively straightforward, but there is still no one product in all people's lives. Aiming at the emphatic watch of empathic company, we surveyed on user experience consumption. According to the survey, the overall design and visual beauty are composite standards, and the data analysis and accuracy are relatively high. However, there are other user experience problems, such as insufficient battery power supply, high radiation impact, and complex interface operation. In Figure 13, the product problems are based on the company's internal research and the evaluation of the product after the purchase of the consumer, which has a more real reference (Figures 14 and 15).

In view of the problems arising from the survey, the author summarizes six directions:

### 4.2.1 Sensor problem

The embodiment of wearable device’s ‘wear’ and ‘wear’ function depends on the sensor’s quality, volume, performance and

| Product                           | Brand             | Product description                                                                 | Problems                                                                 |
|-----------------------------------|-------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Portable intelligent blood        | Huaxiang Shenzhen | According to the pulse wave medical principle, based on photovoltaic sensor, using a unique algorithm to achieve blood pressure measurement | The interface operation sensitivity is low, the data accuracy is low, and the sensor has slight radiation |
| pressure instrument               |                   |                                                                                     |                                                                         |
| Heart rate and blood oxygen       | Tongjie           | Cardiovascular flexible detection and sensing technology and physiological signal micro processing technology were used for measurement | Data accuracy is low; battery power supply is insufficient; volume is too large, not easy to carry |
| detector                          | Communication     |                                                                                     |                                                                         |
| Intelligent snoring pad           | Yushan Shuchen    | Different from the traditional ventilator, bracelet, headphones and other devices that need to be worn, it can improve snoring in an unrestrained way | The treatment effect is good, suitable for single sleeping position, the battery power supply is insufficient |
| Sleepace happy sleep button       | Madija            | It has the functions of sleep monitoring, sleep music, light sleep wake-up and service improvement | Small size, light weight, good data monitoring, but poor sensitivity, touch is not strong |
| iHealth Intelligent Cloud         | Xiaomi            | The first intelligent health accessory, measuring blood pressure with mobile phone, simple operation interface, one button blood pressure measurement | The volume is large, the accuracy of measurement data is not high, and the service scope is small |
| sphygnoomanometer                 |                   |                                                                                     |                                                                         |
| Temperature monitoring            | Ruien Medical Care| Products include temperature wireless management system and central monitoring system | The volume is too large, the operation interface is complex, and the power consumption is large |

**FIGURE 12** Typical products and user experience of wearable technology enterprises in China

| Product                           | Brand          | Product description                                                                 | Problems                                                                 |
|-----------------------------------|----------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Ritmo                             | Nuvo Group     | Help expectant mothers monitor their baby’s heartbeat and activity 24 hours a day   | The volume is relatively large, the data accuracy is insufficient, and there is radiation effect |
| Tmg-BMC Me Sensor                 | Tmg-BMC        | Designed for professional athletes to measure their muscle mechanics under different intensity and exercise | The effect feedback is not good, it is easy to get away from the body during exercise, and the battery is insufficient |
| Scanadu Urine                     | Scanadu        | The instrument measures the chemical content in urine to judge the health status     | The interface operation is complex and not convenient for the elderly    |
| Helius                            | Proteus        | Helius intelligent pill is actually a digestible microchip, which can be absorbed by the intestines and stomach. Combined with the patch on the external skin, it can monitor human characteristics, such as heart rate, breathing and so on | The sensitivity is relatively low, the data accuracy is insufficient, and it is not good for human health after a long time |
| Embrace Watch                     | Empatica       | Smart wristbands designed specifically for patients with epilepsy can help predict seizures | The data has errors, and the monitoring effect is not good, the battery power supply is insufficient |

**FIGURE 13** Product and user feedback of foreign wearable enterprises

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material, and these factors also determine the user experience of product function. At present, the wearable sensors used in clothing can not meet the needs of consumers in terms of volume, quality and materials. The core reason lies in the unnatural combination between the sensor and clothing, and the wearable sensor still needs to be supported by mobile terminals such as smartphones. Another problem is that the design aesthetic feeling of the sensor is poor, and the shape and function of the sensor are not good unified [46].

4.2.2 Human–computer interaction experience is poor

Human–computer interaction is the relationship between people and devices. The feeling of this relationship depends on the user experience of wearable sensors. Generally speaking, in terms of wearable sensors, a good user experience is instant and visual. The sensor itself monitors the physiological data of the human body, so we want to know our physiological data at any time, which is impossible on the current wearable sensors. Few sensors have display screens, and consumers want to know the monitoring results, almost all of them rely on data transmission to mobile phones and computers. On the other hand, even if a few wearable sensors have display screens, they also use touch mode, because the sensor itself is very small and cannot perceive and see data well, so this is also a pain point [48, 49].

4.2.3 Low data accuracy and small service range (wearable computing)

A wearable device is a carrier to obtain data and services in human–computer interaction, and the wearable sensor is the key part [50]. The popularity of wearable devices such as smartwatches and smart bracelets on the market has dropped sharply. One reason is that the accuracy of monitoring data is low, and the type of monitoring is single (heart rate, blood oxygen, step counting, pressure, etc.), and smartphones now have the function of step counting and even heart rate monitoring. Wearable computing is the technology of monitoring data. Due to the problem of sensor volume, the extension of wearable computing function is limited. With the development of algorithm and wearable technology, this problem can be solved effectively.

4.2.4 Low sensitivity of touch technology (human–computer interaction)

There are many ways of human–computer interaction with wearable devices (sensors). Touch technology is one of the important interactive technologies. It is a natural method of human–computer connection and an important revolution in the field of human–computer interaction. Nowadays, touch technology is used in many fields of device interaction interface, because the controller is mature and reliable, low power consumption, and has highly sensitive human–computer interaction performance; but in small wearable devices, due to the limitations of CPU and memory, it is difficult to achieve.

the touch on touch experience that consumers want, which is often said in life The touch screen is sensitive, and the device crashes. This is a common problem of many wearable devices and sensors, hoping to be sensitive in complex situations.

4.2.5 Insufficient battery power supply

Any device needs energy to start, wearable sensor can be considered as one of the most special. Now the biggest pain
point of wearable sensors on the market is the power supply problem. Too large battery leads to too large volume of wearable sensors and bad user experience. Too small battery can not meet the power supply demand of wearable devices, which will lead to frequent charging and cause consumer disgust. Therefore, it is necessary to balance the relationship between function and power consumption.

4.2.6 | The interactivity of the system is relatively low

It is an explicit demand for consumers to purchase and use wearable devices to monitor physiological data, but most users do not only need physiological data. Many users (such as the elderly) have no concept of the data itself, so the accuracy of the data will affect users’ trust in the product, and the accuracy of the data will also affect the formulation of health programs. At present, the medical direction of wearable devices is over from the monitoring end to the mobile end, and the data sharing is not uploaded to the community medical centre, hospital or treatment doctor. This is a common problem. It is not easy to link from the mobile end to the hospital. On the other hand, BAN is still in its infancy, and its application scope and field are relatively small, so it can not complete the multi-interaction of data sharing.

4.3 | Solution

4.3.1 | Multi sensor fusion

As the author mentioned earlier, the highly integrated and diversified measurement of wearable sensors is the future trend. The high integration of sensors can increase the function of wearable devices, and then increase the richness of monitoring data parameters; multiple sensors can be diversified measurement, the system can achieve higher accuracy and obtain more details. In addition, the stable development of BAN can provide a continuous and stable data transmission network for multi-sensor fusion and improve data sharing and interaction.

4.3.2 | Selection of sensor materials with good biocompatibility

The development and application of new materials have always been a driving factor for the development of sensors. It can not only help the wearable sensor achieve a flexible fit with the skin but also be lighter and more sensitive. Due to the limitation of current implantation technology and the reason of human body structure, how to make wearable sensor fit skin more gently is an exploratory problem. At present, the commonly used materials of the flexible wearable sensor include a flexible substrate, metal material, inorganic semiconductor material, and carbon material. In the future, the development direction of wearable devices may be multi-material function fusion, flexible functional materials, mechanical durability of flexible devices, etc.

4.3.3 | High sensitivity at low power consumption

An important challenge for wearable devices is power consumption and power supply. The availability of time between two charges of wearable devices is one of the key factors affecting user experience and market acceptance. Therefore, increasing endurance capacity is the key to the further popularization of wearable devices.

Finally, the future development of the wearable device industry needs to update the stimulation of application points, and users put forward new requirements for the product's deep level information mining function. In the future, wearable devices will integrate a wider range of biosensors, such as spectral sensors for measuring blood oxygen, blood pressure, and blood glucose levels.

5 | DISCUSSION AND RESULTS

5.1 | Sustainable design direction of wearable sensors for clothing in the future

The original meaning of sustainable design is a kind of standard design including environment, economy, society, and culture, which is a universal explanation at present. The author believes that the core of sustainable design is to minimize the negative impact when meeting multi-dimensional needs, which is a two-way beneficial process [51]. At the same time, with the development of artificial intelligence technology, many designers bring artificial intelligence (commonly used as machine learning, algorithm model) into the design. One of the representatives is Buckminster Fuller [52], who was the first to attempt to integrate artificial intelligence into the design. Artificial intelligence represents the technical level, the participation of Technology, and promotes environmental protection innovation, value innovation, and innovation of design Social innovation. A wearable sensor is a typical product of artificial intelligence technology, which has a variety of properties such as systemativeness, data and interaction. Therefore, the author thinks that the demand for wearable sensor for clothing in sustainable design direction is diversified, including diversified precise function positioning, design operation efficiency improvement, heterogeneous data storage and processing, multi-technology deep participation, and design innovation technical requirements. According to the previous problems, in wearable sensors, sustainable design is reflected in many aspects:

5.1.1 | Visibility design

Wearable sensors (devices) are different from smartphones and computers. The volume of wearable sensors is small, so the
visual screen will be very small, and it is not convenient to obtain information. Therefore, in the design, it is necessary for users to accurately see and obtain the required information, which is the basis and essence of the rapid interaction between users and wearable sensors.

The visibility design of a wearable sensor is not only to make vision simple but also to provide useful and accurate content for users. On the visibility design, the author puts forward two suggestions: the sensor interface design is simple and clear, easy to identify; reasonable use of screen size, design the data information that users are most concerned about, and strive to let users get the desired content within 3–5 s.

5.1.2 Identify usage scenarios

Wearable devices are composed of many sensors, which are used to calculate parameters, judge scenes and obtain physiological data. Some information of users in the scene comes from the perception of wearable sensors to the environment, and identify the use scenarios, which is an important design direction in the future. The author thinks that the identification of use scenarios is the result of interaction among the user sensor environment, which is also the key role of BAN in the identification of use scenarios.

5.1.3 Short time human–computer interaction

The interaction between wearable sensors and users must be fast, efficient and effective. Interaction in a very short period of time must be the core requirement of human–computer interaction in the future, and it is also a feature. As far as possible, maintaining human–computer interaction is simple and takes a short time, which is within the acceptable range of users (1–3 s); second, the interaction should be in place in one step, just like the smart bracelet monitoring physiological information changes, and then you need to forward, modify or confirm this information. The best way is not to type or touch, and the most direct way is mutual voice communication.

5.1.4 Reduce the process of interaction

Because it involves the operation and experience of a wearable sensor, the interaction process of the wearable sensor has always been the focus of designers. The famous kiss principle is that we should be restrained from the desire to add (add functions and other information) to a product [53]. More functions and information will break the experience because most users only need a few of them; simple wearable sensor design, strengthen the interaction process, reduce the function information experience, help users quickly obtain the information they need, can let consumers experience the advantages of the product.

Therefore, make the human–computer interaction process simple, highlight the execution of relevant functions, complete one interaction process at a time, and maximize the experience of human–computer interaction as much as possible.

5.1.5 Integrated invisibility

The integration of invisibility is to emphasize the simplicity of the design interface, the user can read or perceive intuitively, and make the human–computer interaction comfortable. The main elements are as follows: the colour and interface contrast make the information readable, especially the content that users are very concerned about; simple font typesetting, font selection of clean and tidy font, so that users can recognize other fonts in many angles or scenes is the first choice; the space of information section in the interface should be appropriate, reasonable use of space, and maximize the user to understand or perceive the interactive data information.

5.1.6 The interference frequency of users is reduced

The smartphones we use often receive system notification, which is a kind of information interference for most people. In wearable sensors, this interference experience will be magnified and irritating. At the same time, wearable sensors interact with people for a long time, which is unavoidable.

The author puts forward the following elements: filter out the less critical information notification, and reduce the push frequency; understand the actual needs of users, and ensure that the notification is important and high-quality when it is needed; allow users to freely set the time and type of notification, so that they can choose the most suitable way.

5.1.7 Privacy and security

Privacy and security in the future artificial intelligence society are one of the most attractive design points for users. Therefore, privacy and security need to be designed: understand the content and display mode of a wearable sensor, and set different display modes; system notification can set vibration first, and then display the notification information [54].

5.1.8 Multi interaction, multi-point connection

Multi interaction and multi-point link is the concept of BAN proposed here. Let every wearable sensor participate in the ecological, organized and shared network threshold, so that more users and organizations can know your condition (health), which is the general trend of medical health wearable in the future.

5.1.9 Off line communication

In order to deal with the use of multiple scenarios or complex conditions, a wearable sensor must be online all the time, with
good signal and conditions for data transmission. If the wearable sensor leaves the network support, the core functions of the wearable sensor can still work well.

6 | CONCLUSION

2020 an unforgettable year for all countries in the world. The popularity of COVID-19 has attracted more attention to sensor technology, including tracking the early onset of new crown disease, using wearable devices for contact tracking, and remote monitoring of isolated patients. This is a wearable sensor applied in the field of medical and health, so the research and development of wearable sensor in the future Exhibition is an increasingly important direction.

According to the background, current situation and problems of the wearable sensor, the author analyses the solutions of wearable sensor for clothing, and puts forward several directions for sustainable design of wearable sensor in the future, which is also a hot point in the design of wearable sensor at present. In general, the sustainable design direction of wearable sensors can be summarized as three points [51, 55]:

1. Intelligent control technology. Intelligent control technology currently includes two parts, one is wireless transmission technology and sensor sensing technology. From the wireless transmission technology, often used, will there be electromagnetic radiation or skin damage? And whether it will cause physical harm to the surrounding organisms (animals sensing the outside world), which requires the wearable device itself and the wireless transmission technology to be sustainable; in sensor sensing technology, the sensor recognizes the voice and behaviour expression of the user, and also uses bone conduction to sense the action and sound, so that the user experience will be more practical and digital the acquisition will be more accurate.

2. Flexible material innovation technology. At present, in the frontier field of intelligent clothing, there are many achievements and problems. Flexible wearable sensors, flexible skin, flexible biomaterials and flexible patches are the results of future flexible material innovation. The current biosensor is an integrated platform, which is closely combined with skin and blood, and has far-reaching impact value. In flexible materials, users, clothing and environment are fully connected, which reflects the meaning of sustainable design.

3. Sustainable interaction. Here mainly refers to human–computer interaction and human-environment interaction. From the perspective of interpersonal interaction, it is mainly a direction of active interaction in the future, and BAN network is also a medium in the human–computer interaction relationship; from the perspective of interaction between human and environment, for example, when encountering toxic gases, particles or dangerous conditions in the air or environment, how can personal injury be avoided? If the clothing is attached with special coating materials or placed with micro monitoring sensors, it can achieve early warning mechanism and alarm; intelligent clothing is a real object, which needs to highlight some specific functions in a specific environment, such as using VR and AR technology to simulate the user experience of intelligent clothing in a specific environment, which will be valuable in user use and operation feedback.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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