

# An Overview of the Miniaturization and Endurance for Wearable Devices

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**Abstract:** The miniaturization and endurance of wearable devices have been the research direction for a long time. With the development of nanotechnology and the emergence of microelectronics products, people have explored many new strategies that may be applied to wearable devices. In this overview, we will summarize the recent research of wearable devices in these two directions, and summarize some available related technologies.

**Keywords:** Wearable equipment; miniaturized equipment; body sensor network; flexible antenna; low power consumption; micro generator

## 1 Introduction

Since the concept of wearable devices was put forward in the middle of the 20th century, the development of wearable devices has changed rapidly. It is applied to not only medical devices based on cloud computing data, but also gesture recognition and personalized clothing which is used to know the daily state information of human body. People always expect that the wearable devices can be more and more light, so that we can live and work better. However, the complexity and bulkiness of equipment is still an important problem at present. At the same time, it is still a huge challenge for a single device to achieve high-performance energy storage to obtain stable, self powered, multifunctional and miniaturized integrated system [1]. For the purpose of equipment refinement, silicon micromachining have developed rapidly [2]. As a result, the equipment needs to be more refined and precise. While processing, it will undoubtedly increase the difficulty of design and increase the consumption in production. In addition, the nano materials will develop rapidly, too. With the support of nano materials, biosensors applied to human body continuously will improve the detection accuracy and analysis performance of sensors, which will provide great help to reduce the burden of human wearing [3]. In addition, low-power application design is another important task for people to study wearable devices. Among them, BLE (Bluetooth Low Energy) is a good example. This new low-power wireless technology, developed for short-range control and monitoring applications, is expected to be integrated into billions of devices in the next few years [4]. With the development of this technology, it can greatly reduce the energy consumption of the equipment, prolong the working time, produce lower heat output and prolong the service life of the equipment, so as to reduce people's trouble in wearing the equipment.

This paper will divide the main content into two parts. The first part introduces the development and breakthrough of wearable devices in the field of miniaturization, especially the miniaturization of sensors. The second part will introduce a variety of methods for the durable endurance of wearable devices, aiming to maximize the endurance of the device in the limited technology. At the end of the paper, it summarizes the whole paper, pointing out the other space for development of wearable devices and the expectation for the future development.

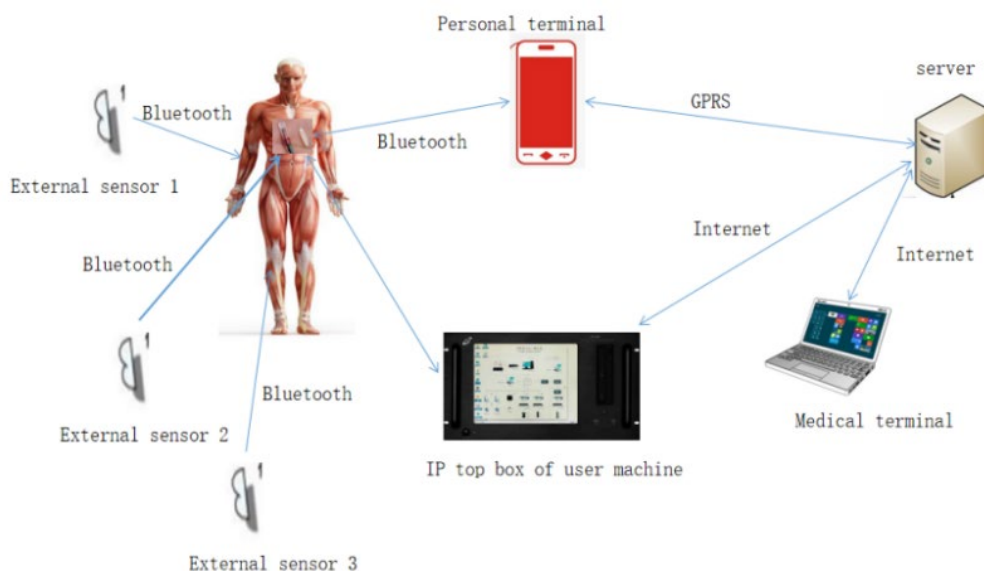


## 2 Miniaturization

The miniaturization of wearable devices is mainly reflected in the refinement of sensors. Unlike ordinary sensors, wearable devices need to contact with human body or be assembled on clothes or accessories. Therefore, it can be generally divided into contact wearable device and non-contact wearable device. Next, we will introduce the application in miniaturization according to this classification. Among them, most of the current contact wearable devices are directly equipped with a variety of sensors on the skin of the body to build the body sensor network, to get the information of human body. However, the non-contact equipment platform gets the information through smart wearable equipment.

### 2.1 Miniaturization of Human Body Sensor Network

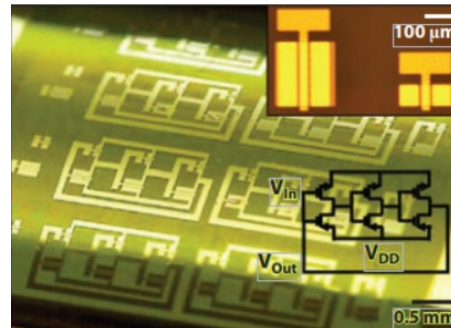
BSN (Body Sensor Network) takes the body as the core, and integrates multidisciplinary such as biosensor, medical electronics, multi-sensor analysis and data fusion, artificial intelligence, universal sensor, wireless communication and other innovative applications. This new human detection technology mainly obtains the physiological characteristics of the human body through various sensors installed on the human body, and then sends the characteristic information to the end-user equipment (laptop and personal computer) through wireless devices such as Bluetooth for further analysis [5]. In fact, the platform of human body sensor network is also the wireless network hardware platform, most of which are designed for network research, environmental monitoring or tracking applications [6]. As for the miniaturization of body sensor network, it is mainly to solve the problem of miniaturization design on various sensors. Fig. 1 is the system framework of body sensor network.



**Figure 1:** The frame structure of body sensor network

In reference [7], there is a kind of electrochemical humoral sensor for medical detection. This non-invasive sensor mainly uses the plane electrochemical cell technology based on miniaturization to measure the biological body fluid, such as human sweat, and then analyzes the concentration of a biomarker in the body fluid, so we can get other difficult physical and chemical parameter information in the organism. The data transmission module and the miniaturized wireless power supply can also reduce the occupied space of the device to a large extent. In addition, in order to further miniaturize the device, the data acquisition module can be replaced by more variability modules [8]. For example, in reference [9], a flexible and scalable field-effect semiconductor transistor is introduced, which can still be flexibly applied to integrated circuits in high-level deformation. Fig. 2 shows the flexible circuit on this transistor. In fact, graphene with high charge carrier mobility [10] and inherent elastic strength [11] at room

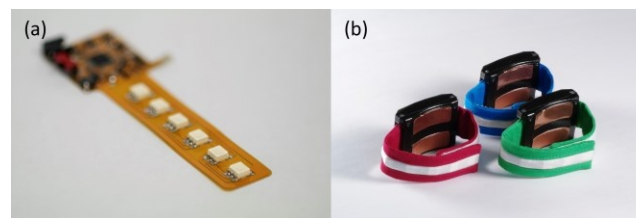
temperature also has the potential to develop tensile devices. The properties of graphene in electricity, optics, heat and mechanics are introduced in reference [12], and the application of graphene in hybrid materials and nano materials is pointed out. Recently, the substrate selected for the micromachining of graphene devices is silicon oxide wafer, because it has better dielectric properties. However, oxide materials are easy to cause substrate roughness, and the stability is not strong enough to the outside [13]. Yamada et al. [14] have studied a miniaturized chemical resistance gas sensor which can be used for skin monitoring directly. It uses the reaction between zeolite and acetone produced by skin perspiration to monitor fat metabolism. The device improves the related plasma film by considering the relationship between the dielectric constant of the nano oxide semiconductor and the substrate, which can further reduce the influence of external light and heat on the measurement.



**Figure 2:** The flexible circuit with transistors

## 2.2 Miniaturization of Intelligent Wearable Devices

Because sensors are not easy to attach directly to the human body in many cases, we need some intelligent wearable devices to solve the problems people encounter. The level of intelligent wearable devices will not be sensors, but all kinds of intelligent devices in human body, such as watches, glasses, bracelets, etc. In addition, some sensors are installed on clothes to achieve the goal of detection. As described in reference [15], smart vest can be used as a wearable physiological monitoring system to obtain parameters of heart rate, blood pressure, body temperature, etc. In addition, intelligent wearable devices can be used not only to detect physical conditions, but also to enhance the relationship between people. For example, a kind of intelligent bracelet popularized to the outside world in reference [16] provide stronger touch interaction for children with ASD (Autism Spectrum Disorder). The product prototype is shown in Fig. 3. These intelligent wearable devices are also becoming lightweight and convenient [17].



**Figure 3:** Prototype: (a) The flexible circuit with one pan module and six full-color LEDs; (b) The battery and circuit installed in the plastic device of cloth belt and Velcro

At present, the miniaturization of many intelligent wearable devices is embodied in the flexible fabric antenna, which can smoothly integrate small electronic products into clothing [18]. For example, Bappaditya Mandal et al. [19] introduced a new compact textile button antenna that can be installed on clothes as a button. When people communicate with each other wirelessly, it can reflect any interaction of people's activity, location and surrounding environment. At the same time, the relevant research on the design of antenna parameters is also introduced in reference [19]. In reference [20], a design method of

Super bandwidth quasi self complementary antenna is introduced. It can not only meet the requirement of antenna lightness and miniaturization, but also realize the impedance bandwidth of 10 dB without matching circuit. Since then, Faruk Hasan et al. [21] used the wear-resistant and flexible leather substrate as the manufacturing substrate to replace the original FR-4 substrate. This will reduce the size of the Super bandwidth quasi self complementary antenna to 1/3 of the original system, and it can even be used on human wrist. In order to obtain flexible materials with greater flexibility, in reference [22], it is introduced that LiZnTiBi ferrite with high permeability can be synthesized at low temperature, and its particles can be used to prepare a flexible PDMS(Polydimethylsiloxane) based film. It is a great breakthrough in the field of wearable sensor electronics. In the same year, maria et al. [23] realized an ultra-thin and compact CPW(Cost Per Wear) feed slot monopole antenna for Internet of things (IoT) applications by exploring the use of a new type of zirconia, based flexible ceramic (ENrG thin E-Strate) for antenna design.

The following table compares the information of some flexible materials.

**Table 1:** Manufacturing methods and characteristics of different flexible materials

Flexible material	Composition	Characteristic
Nano conductive cotton [23]	Metal oxide nanoparticles, nanowires, conductive	Wear resistance, good mobility, high field effect,
ENrG's Thin E-Strate [24]	Ultra thin flexible ceramic material	High mechanical strength, high temperature resistance
PDMS [25]	Organic polymer materials based on silicon	Stable response signal, high sensitivity and good strain

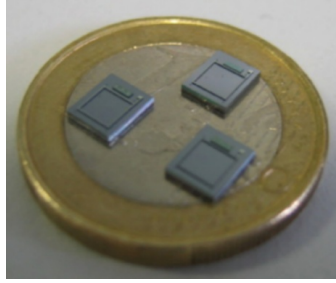
### 3 Endurance

For wearable devices, we think about it in two ways. On the one hand, we can prolong the service life of wearable devices by reducing the use power of wearable devices and carrying new power technology. On the other hand, we can also improve the endurance of the wearable device by assembling some micro power generation devices on the human body. This kind of power generation device mainly uses the collected human secretion or the captured physical state to convert into the working power supply of wearable devices. Then, we will introduce these two methods to improve the endurance of wearable devices in detail.

First of all, in order to improve the power capacity of the equipment, the flexible super capacitor is produced. In reference [26], a paper battery based on carbon nanotube film is introduced, which has low resistance, light weight and excellent flexibility, and it enables long-term mechanical flexibility. However, its application on the online energy storage device is rare, and it is difficult to distribute itself in a large range of clothing. Therefore, in reference [27], a kind of high-performance linear super capacitor and micro battery has been developed by using oriented multi-walled carbon nanotubes as electrodes. Subsequently, a three-dimensional interconnect hybrid hydrogel system based on the CNT (Carbon nanotube) conductive polymer network structure is reported in the literature [28]. It has high electrical conductivity and high strain tolerance, so it has great potential to be used in the preparation of various high energy batteries. In addition, combined with the antenna device mentioned above, if the current consumption can be minimized in communication, the power consumption will also be reduced to a certain extent. For example, according to the communication data transmission and the sleep interval time of the antenna equipment, Artem et al. [29] proposed an optimal sleep interval measurement method that can balance power consumption and data rate. This technology can also be used as the basic system of the IoT. From the comparison of performance and energy consumption of different mobile gateways in different applications in reference [30], it can be seen that more complex computing is left to mobile devices, while other simpler application stages used on wearable devices can reduce energy consumption.

In addition to reducing the power consumption of its own devices, it is also a good way to add some micro generators into the wearable devices to power other electronic devices.

When people are exercising, the body will produce a lot of heat and part of the secretion. These will provide raw materials for the micro generator. For example, reference [31] introduces a small wearable generator specially designed for human application. It is mainly composed of micro processing thermopile chips less than the size of a euro coin, which can realize certain energy monitoring. The micromachined thermopile chip is shown in Fig. 4. Since then, Wang et al. [32] have developed a new hot spot generator with wearable triethylene glycol to collect human heat. It can reduce the impact of the external environment and provide power for the micro acceleration sensor better.



**Figure 4:** Microchip of micro processing thermopile arranged on one euro coin

However, the detection of heat cannot completely overcome the impact of external environmental factors, which makes people focus on the flexible friction generator. This is a kind of power generation equipment that can convert mechanical energy into electrical energy. It is made of two polymer films made of materials with obviously different triboelectric properties. Once mechanical deformation occurs, due to the nanoscale surface roughness, the friction between the two films will produce equal but opposite charge signs on both sides [33]. In order to increase its service life and high output power, a flexible friction energy Nanogenerator with PDMS and PDMS/MWCNT (Multi-walled carbon nanotube) double-sided friction layer is proposed in reference [34]. MWCNT of different concentrations is doped into PDMS to adjust the internal resistance of the friction nanowave generator and optimize its output power. If there is friction, due to the large difference in affinity between the two materials, electron will transfer. The relationship between the output current  $I$  and the transferred charge is shown in Formula (1):

$$I = \frac{\Delta Q(t)}{t} \quad (1)$$

$\Delta Q(t)$  represents the total number of electrons transferred in time  $t$ . In addition, based on the theoretical research in reference [35], the differential equation of transferred charge can be expressed as shown in Formula (2):

$$\frac{\Delta Q(t)}{t} = \frac{[Q - \Delta Q(t)]X(t)}{A\varepsilon_0 R_e} - \frac{\Delta Q(t)d_1}{A\varepsilon_0\varepsilon_1 R_e} - \frac{\Delta Q(t)d_2}{A\varepsilon_0\varepsilon_2 R_e} \quad (2)$$

$Q$  represents the total charge on the surface of the material,  $X(t)$  represents the equation of motion interval [35],  $A$  represents the area of the material surface,  $R_e$  is the external load resistance,  $\varepsilon_0$  is the vacuum dielectric constant,  $\varepsilon_1$  and  $\varepsilon_2$  represent the permittivity of PDMS and PDMS/MWCNT respectively,  $d_1$  and  $d_2$  are the thickness of PDMS and PDMS/MWCNT, respectively.

#### 4 Conclusion

This paper reviews two aspects of wearable devices: Miniaturization and improvement of endurance. In the process of miniaturization, we review the description of contact and non-contact, and list some

miniaturization schemes that are in the research currently. In order to improve the endurance, we not only introduce some low-power applications which can be used in wearable devices, but also mention several micro generators which can be used with wearable devices. At present, human beings are still doing further research for the development of these two aspects. In addition, wearable devices have great development space in intelligent, Internet of things applications and virtual reality technology. We hope this paper can give readers enlightenment and further develop the potential development space of wearable devices.

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