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Wearable ubiquitous energy system

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In recent years, owing to the growing maturity of Internet of Things technology and mobile communication technology, intelligent wearable devices have developed rapidly. They have been widely applied in aviation, medicine, military, entertainment and other fields. Through intelligent wearable devices, people can communicate efficiently, dynamically perceive external environments, and monitor the body's vital signs. The devices can also timely feedback and process information [1, 2]. However, on the one hand, wearable devices are restricted by the requirements of comfort, portability and miniaturization. On the other hand, traditional batteries also have problems such as large quality, large volume, short battery life and limited power supply life. In addition, non-active power generation has low power density and poor continuity, which is not enough to support equipments for a long time. Energy supply has been the bottleneck restricting further development of wearable devices.

Therefore, this study proposes a wearable ubiquitous energy system. Through wearable clothes and devices, ubiquitous energy such as solar energy, thermal energy and mechanical energy generated by human movements can be efficiently harvested, which can be converted into electric energy for comprehensive utilization. It can not only avoid the environmental limitation of single energy supply, but also meet the energy demand of normal use of low-power wearable devices. This is a powerful means to solve the energy supply problem of smart wearable devices.

Ubiquitous energy harvesting. Different types of ubiquitous energy have very different harvesting mechanisms. The following three kinds of energy harvesting devices are designed according to different use environments, as shown in Figure 1.

(1) Solar energy. Solar energy is widely found in nature and contains huge energy. Solar energy can be converted into electric energy by utilizing the photovoltaic conversion characteristics of semiconductor materials. The most effective combination of solar harvesting and wearable concept is to make solar clothes as shown in Figure 1(a). The improvement of conversion efficiency and the development of flexible solar-cell technology have laid a foundation for the energy harvesting device in solar clothes. When walking normally, the back of the body is exposed to sunlight for a long time. Multiple flexible solar cells are connected by wires to form a flexible solar array that is placed on the back of clothes. The solar array becomes a part of solar clothes, and whole clothes are light. In the case that there is no external power supply for a long time, the wearable solar clothes can convert continuous solar energy into electric energy to supply portable devices.

(2) Thermal energy. There is a temperature difference between a human body and an external environment. Using temperature differences to generate electricity is the most efficient way to harvest wearable thermal energy, which is based on the Seebeck effect. When the two ends of the thermoelectric generator (TEG) are at different temperatures, the voltage difference will be generated, thus converting the temperature difference between the hot source and the cold source into electric energy. TEGs are arranged on flexible circuit boards in series and parallel to form thermoelectric modules. Thermoelectric modules are arranged on the front of sports tights to make thermoelectric clothes [3], as shown in Figure 1(b)-1. Only when the TEG is in close contact with human skin can the energy be harvested and converted effectively. Therefore, the design of tights can avoid the loss of power generation efficiency caused by poor contact and use the potential thermal energy reasonably and efficiently.

To make full use of thermal energy, an ordinary kettle is improved to make a wearable thermoelectric kettle as shown in Figure 1(b)-2. The TEGs are placed on the kettle base, which is connected with the kettle body by screws. So the TEGs are in close contact with the base and body of the kettle. The bottom of the kettle body is in contact with the cold end of the TEGs. The kettle body with a toothed radiator can increase the contact area with water and get better water-cooling effect [4]. The hot source is the fire for heating water and the cold source is the cold water in the kettle. In the process of boiling water, the kettle can convert the temperature difference into electric energy.

(3) Mechanical energy. Considerable mechanical energy

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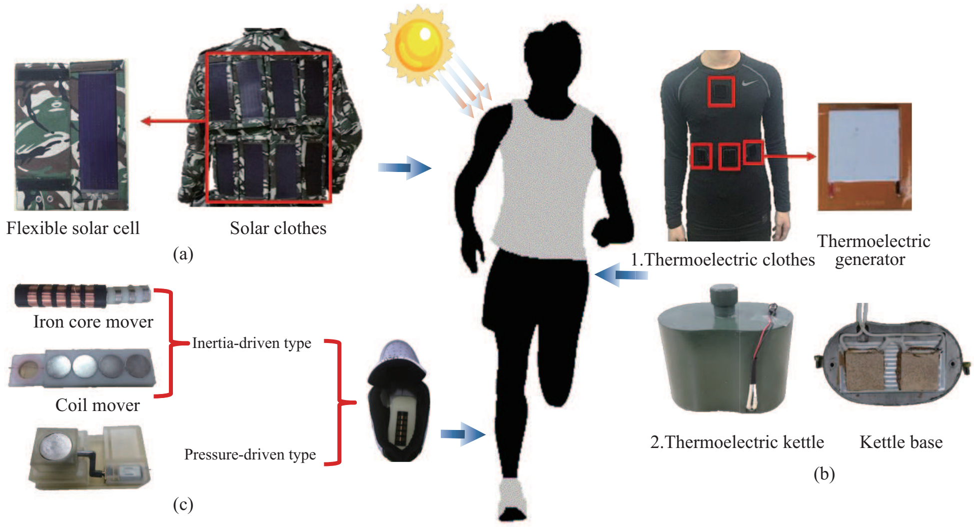

Figure 1 (Color online) Ubiquitous energy harvesting devices. (a) Solar energy harvesting device; (b) thermal energy harvesting device; (c) foot mechanical energy harvesting device.

can be harvested from normal human activities, such as the rotation of human joints and the loading of gravity. The efficient conversion of mechanical energy into electrical energy can improve the utilization of human energy, and this passive way of harvesting mechanical energy does not affect human normal activities. According to the principle of electromagnetic power generation, the human foot mechanical energy harvesting devices driven by inertia and driven by pressure are designed as shown in Figure 1(c). The mechanical energy harvesting devices are installed in the characteristic insole and placed on the heel. It can not only achieve energy conversion, but also play a role of buffer for protection from sport injuries. The inertia-driven device uses the inertia of the foot when the human body is walking to drive a inertia mover, thus cutting the magnetic induction line and generating the induced current to generate electricity. Both the coil and the iron core can be used as movers [5, 6]. The pessure-driven device takes the small dc motor as the main body of power generation, and uses pressure of foot stepping to drive the transmission shaft, so that the motor generates electricity [7]. These mechanical energy harvesting devices convert mechanical energy of human foot movements into electric energy.

Ubiquitous energy control. Wearable ubiquitous energy harvesting devices are arranged around the human body, and the working environment is very special. The movement process and temperature changes are dynamic and complex. Therefore, the power generated by ubiquitous energy is closely related to the external environment and human body states, and may fluctuate greatly under the influence of external factors. In order to maintain the self-power demand of wearable devices, the comprehensive control of ubiquitous energy is needed.

For solar energy harvesting, when multiple flexible solar cells are used dynamically, there will be multiple peaks and voltage bands, and the maximum power point will move according to the temperature and irradiation conditions. For thermal energy harvesting, the output power of the semiconductor thermoelectric generator also shows a parabolic shape with the change of the output voltage. In order to improve the energy conversion efficiency, it is necessary to track the maximum power point and make the output voltage work at the corresponding position of the maximum power point. At the same time, the energy of wearable ubiquitous energy harvesting system is too limited to support a high-power control algorithm. Therefore, it is necessary to design low-power control devices and algorithms to ensure the reliability of the system.

Based on the above requirements, The solar energy harvesting system uses voltage band control algorithm to make the solar cells work at the maximum power point [8]. The thermal energy harvesting system adopts modified perturb-and-observe algorithm to achieve the maximum output power [9]. These maximum power point tracking (MPPT) algorithms enable wearable solar and thermal energy harvesting systems to provide a stable maximum power output under any light intensity and temperature conditions. Thus, the power supply time is extended with the least algorithm power consumption and the maximum power output.

Ubiquitous energy storage. At present, traditional batteries, such as lithium batteries, are mainly used for energy storage. However, traditional batteries have many problems, such as large weight, large volume, limited energy supply life, regular replacement, material waste, and environmental pollution. The supercapacitor as an energy storage device provides a new way of wearable ubiquitous energy storage. It is a device between the ordinary capacitor and the accumulator, and has large capacity, high power density and good effect of storing low power energy.

In view of the requirements of wearable comfort, we need flexible energy storage components to realize energy storage. The flexible solid-state supercapacitor, which has the same performance as ordinary supercapacitors, is currently under laboratory study. Its shape is similar to that of cloth. It is very flexible and suitable for wearable systems. The obtained ubiquitous energy can be stably and efficiently stored in flexible solid-state supercapacitors. The flexible supercapacitor is arranged on the thermoelectric clothes [3], which shows a good energy storage effect for low-power generating equipment and can be well combined with the clothes.

Conclusion. In this study, we proposed a wearable ubiquitous energy system, which is a distributed non-active self-power plan of wearable devices. For three of the most promising ubiquitous energy sources: solar, thermal and mechanical energy, we discussed the harvesting equipment, control methods and storage methods. The key technologies of ultra-low power conversion control and flexible storage for ubiquitous energy under dynamic conditions were studied, which improve the conversion efficiency of ubiquitous energy and wearable comfort, and provide new ideas for energy supply of wearable devices. In the future, the links between various ubiquitous energy will be further strengthened. The comprehensive control and conversion of ubiquitous energy under dynamic conditions will be further studied to realize the integration of multiple ubiquitous energy. It is hoped that the complementary continuous energy supply can be realized by using integrated energy dispatching. In this way, we can better solve the problem that a single energy source cannot supply energy all the time.

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