Wearable Ubiquitous Energy System

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Contents

1.Introduction

Background

- In recent year, intelligent wearable devices have developed rapidly. They have been widely applied in aviation, medical, military, entertainment and other fields.
- 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.
- Energy supply has been a bottleneck restricting the further development of wearable devices.

1.Introduction

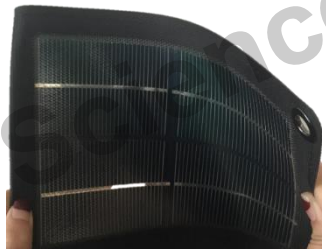
- This paper proposes a wearable ubiquitous energy system.
- Through wearable clothes and devices, ubiquitous energy such as solar energy, thermal energy and mechanical energy generated by human movement can be efficiently harvested, which can be converted into electric energy for comprehensive utilization.
- This is a powerful means to solve the energy supply problem of smart wearable devices.

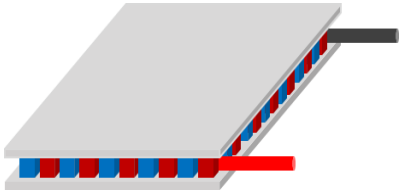
2.Ubiquitous energy harvesting

- **Different types of ubiquitous energy have very different harvesting mechanisms.**

Ubiquitous energy

Solar energy	Thermal energy	Mechanical energy	Other energy
Sunlight	Temperature difference	Tread	Others



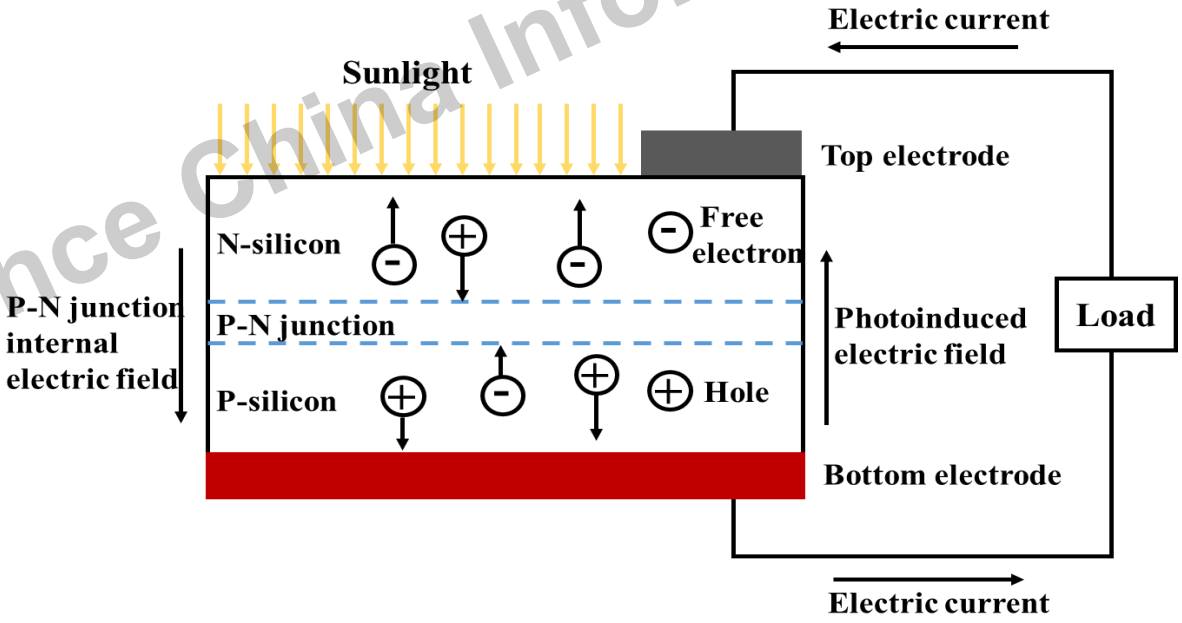


Wearable ubiquitous energy system

2.Ubiquitous energy harvesting

(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.



Photovoltaic cell realizing photoelectric conversion process

2.Ubiquitous energy harvesting

(1) Solar energy

- The most effective combination of solar harvesting and wearable concept is to make **solar clothes.**
- Multiple flexible solar cells are connected by wires to form a flexible solar array that is placed on the back of clothes.
- The wearable solar clothes can convert the continuous **solar energy** into **electric energy** to supply portable devices.

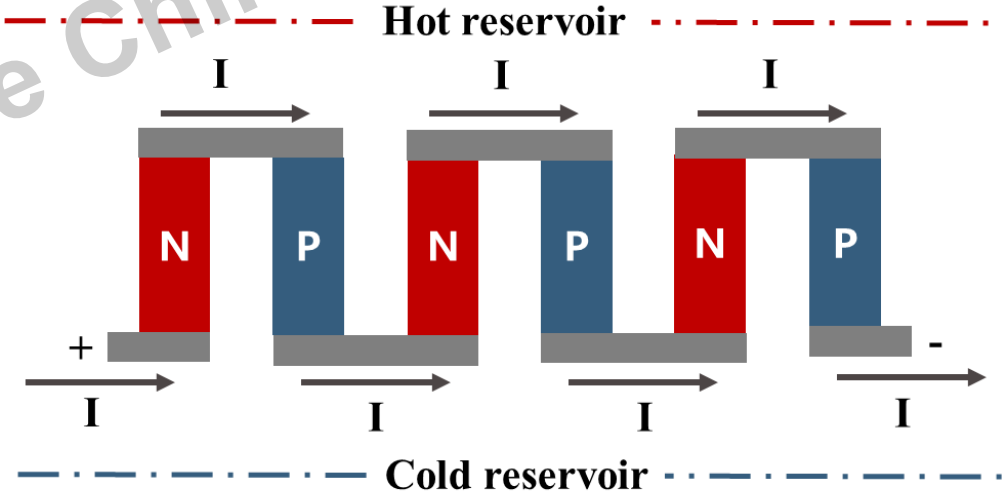
Solar energy harvesting device

Actual wearing effect

2.Ubiquitous energy harvesting

(2) Thermal energy

- Using **temperature differences** to generate electricity is the most efficient way to harvest wearable thermal energy.
- The principle is the **Seebeck effect**.
- When the two ends of the thermoelectric generator(TEG) are at different temperatures, the voltage difference will be generated.

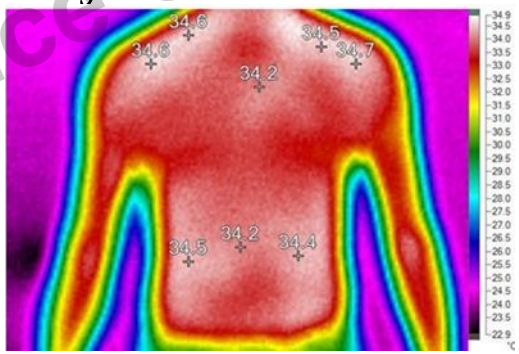


Thermoelectric generator structure

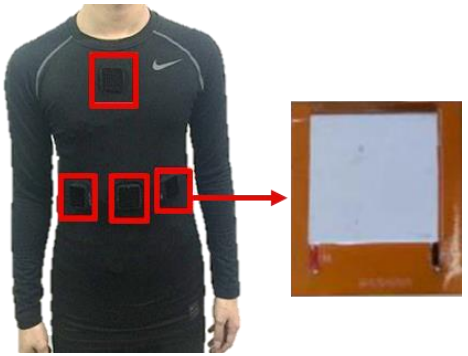
2.Ubiquitous energy harvesting

(2) Thermal energy

- **TEGs are arranged on flexible circuit to form thermoelectric modules. Thermoelectric modules are arranged on the front of sports tights to make thermoelectric clothes.**
- **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.**



Infrared scanning of human body [1]



Thermoelectric clothes

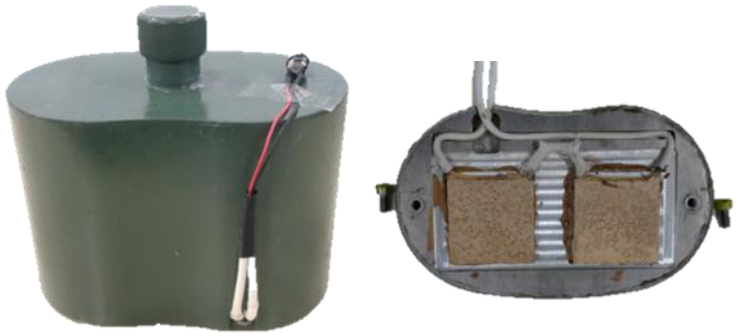
[1] Deng F, Qiu H, Chen J, et al. Wearable thermoelectric power generators combined with flexible supercapacitor for low-power human diagnosis devices[J]. IEEE Transactions on industrial electronics, 2016, 64(2): 1477-1485.

2.Ubiquitous energy harvesting

(2) Thermal energy

- The ordinary kettle is improved to make **wearable thermoelectric kettle**.
- The TEGs are placed on the kettle base, which is connected with the kettle body by screws. The hot source is the fire for heating water，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**.

The temperature field contours of heating water[2]



Wearable thermoelectric kettle

[2] Li Y, Deng F. Modeling and simulation of thermoelectric power generation system based on finite element method[C]//Proceedings of the 33rd Chinese Control Conference. IEEE, 2014: 6388-6393.

2.Ubiquitous energy harvesting

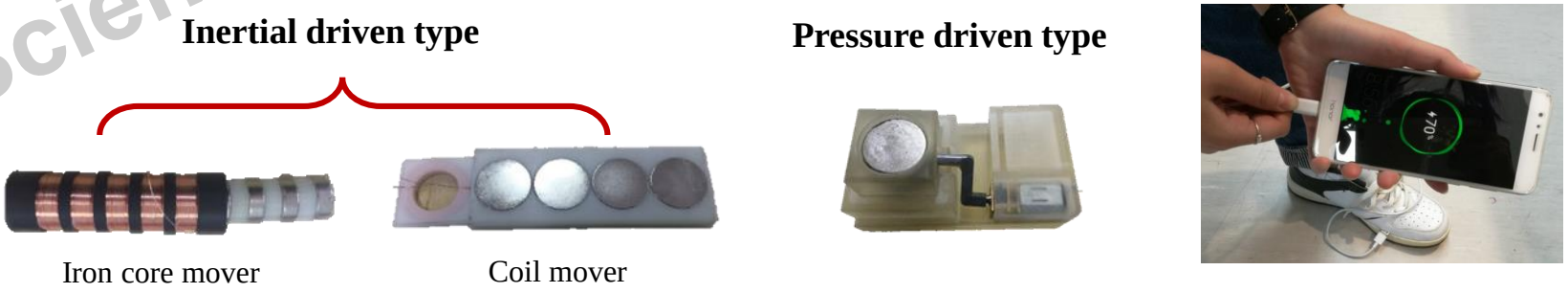
(3) Mechanical energy

- Considerable mechanical energy can be harvested from normal human activities .
- 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.

2.Ubiquitous energy harvesting

(3) Mechanical energy

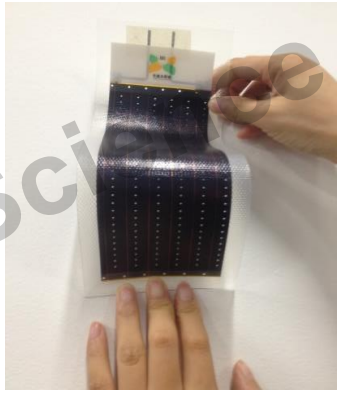
- **Inertial driven type** uses the inertia of the foot when the human body is walking to drive the mover, thus cutting the magnetic induction line and generating the induced current to generate electricity.
- **Pressure driven type** takes the small dc motor as the main body of power generation, and uses the pressure of foot stepping to drive the transmission shaft, so that the motor generates electricity.



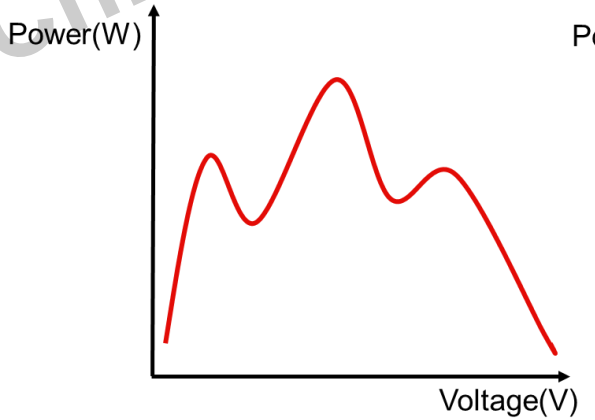
Foot mechanical energy harvesting device

3.Ubiquitous energy control

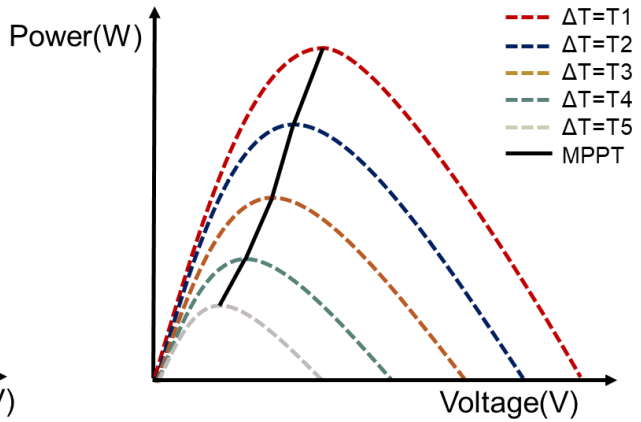
- **The movement process and temperature changes are dynamic and complex. The power generated by ubiquitous energy is closely related to the external environment and human body state.**
- **In order to improve the energy conversion efficiency, it is necessary to track the maximum power point and make the output voltage work at the corresponding position of the maximum power point.**



Flexible solar cell



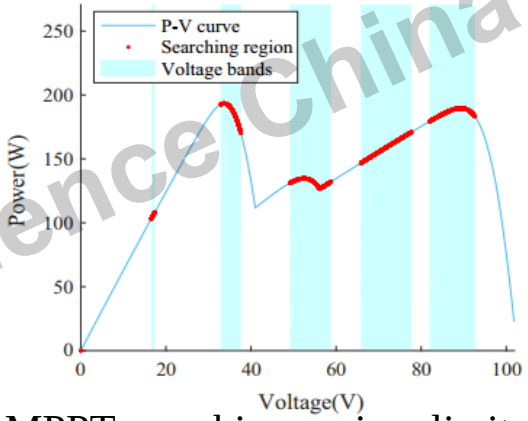
Solar cell P-V curve under dynamic conditions



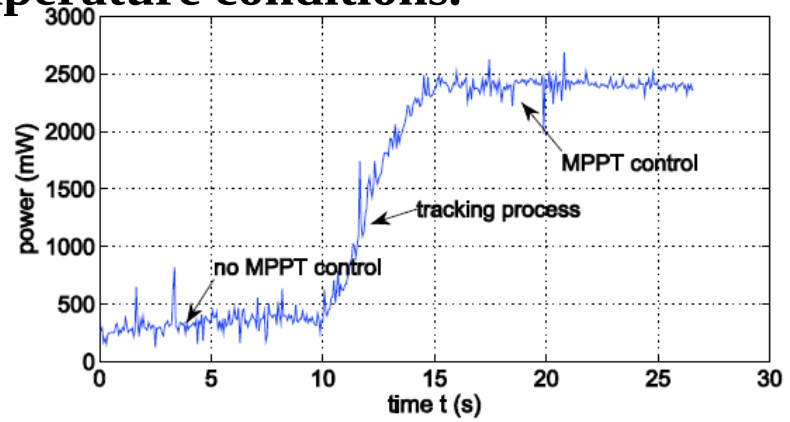
Thermoelectric generator P-V curve in different ΔT

3.Ubiquitous energy control

- **The solar energy harvesting system uses voltage band control algorithm to make the solar cells work at the maximum power point.**
- **The thermal energy harvesting system adopts modified perturb and observe algorithm to achieve the maximum output power.**
- **These MPPT algorithms can provide a stable maximum power output under any light intensity and temperature conditions.**



The MPPT searching region limited to a smaller range [3]



The output power of thermoelectric generator with MPPT[4]

[3] Fan X, Deng F, Chen J. Voltage band analysis for maximum power point tracking of stand-alone PV systems[J]. Solar Energy, 2017, 144: 221-231.[4] Xie W, Huang G, Zhang X, et al. A maximum power point tracking controller for thermoelectric generators[C]//2017 36th Chinese Control Conference (CCC). IEEE, 2017: 9079-9084.

4.Ubiquitous energy storage

- **Traditional batteries have many problems, such as large weight, large volume, limited energy supply life, regular replacement, material waste and environmental pollution.**
- **The Supercapacitor is an energy storage device between ordinary capacitor and accumulator, and has large capacity, high power density, good effect of storing low power energy.**

Accumulator

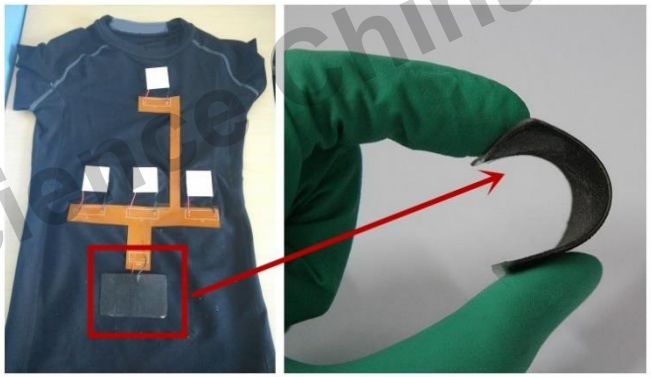
Cylindrical supercapacitors

Disc supercapacitor

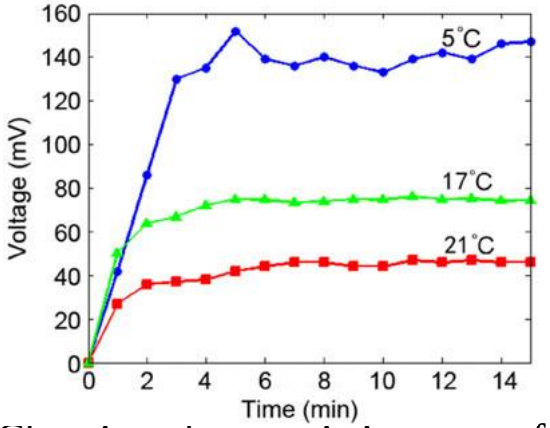
Flexible supercapacitor

4.Ubiquitous energy storage

- **The flexible solid-state Supercapacitor has the same performance as the ordinary supercapacitor. 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.**



Flexible supercapacitor arranged on the thermoelectric clothes [1]



Charging characteristic curve of the flexible supercapacitor [1]

[1] Deng F, Qiu H, Chen J, et al. Wearable thermoelectric power generators combined with flexible supercapacitor for low-power human diagnosis devices[J]. IEEE Transactions on industrial electronics, 2016, 64(2): 1477-1485.

5.Conclusion

- In this paper, we propose wearable ubiquitous energy system.
- For the three 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 of wearable ubiquitous energy under dynamic conditions were studied, which improve the conversion efficiency of ubiquitous energy and wearable comfort.
- In the future, the links between various ubiquitous energy will be further strengthened to realize the integration of multiple ubiquitous energy.

THANK YOU!