Energy Harvesting For Wearable Devices

UNIT III (PART II) FOR UNDERSTANDING PURPOSE

OVERVIEW

- In recent years, wearable devices have attracted attention because of their ability to enhance the quality of life.
- This disruptive technology has helped healthcare professionals with intervening early in chronic diseases, especially amongst independently living patients, and has facilitated real-time monitoring of patients' vital signs remotely.
- One of the major bottlenecks that hamper the adoption of wearable device is the continuous power supply. Most wearable devices solely depend on battery supply.
- When the energy stored in the battery is depleted, the operation of wearable devices is affected. To overcome this limitation, efficient energy harvesters for wearable devices are crucial

OVERVIEW[2]

- THE ageing population has been growing at an unprecedented rate worldwide owing to the improvements in quality of life. United Nations estimated that by 2017, over 962 million people worldwide would be over the age of 60 years.
- The number of elderly people will further increase to 1.4 billion by 2030 as fertility declines and life expectancy rises [1].
- Many publicly funded healthcare systems are facing massive increases in costs and crowdedness in medical institutions owing to the need for nursing care.
- Many of these patients are diagnosed with obesity and diabetes, chronic diseases that can be prevented with appropriate diet and sufficient physical activity

- Unlike wireless sensor networks, timely delivery of data from a device to the cloud server is crucial because several wearable devices are used in emergencies, such as detecting falls and heart attack. Any delay may potentially cost a person their life.
- Therefore, a continuous source of electrical power is crucial to prevent interruption of the operation of wearable devices [12].
- However, energy limitations remain a critical constraint because many wearable devices are powered solely by battery energy. When battery energy is depleted, health monitoring will be interrupted until the battery is charged or changed.

- Wearable devices should be easy to use and require low levels of maintenance. These devices should be able to operate continuously with minimal human intervention [13].
- The use of large-capacity batteries in wearable devices increases the size and weight of these devices, making them unattractive for use and causing discomfort to users [14]. An ideal wearable device should be invisible or resemble a fashion item

ENERGY HARVESTING TECHNIQUES IN WEARABLE DEVICES

- Generally, wearable devices are composed of sensors for monitoring vital signs; they have low-power processing capabilities to process the vital sign signals so that they can be visualized by healthcare providers.
- Such devices perform tasks such as collecting signals from sensors, processing them and storing and transmitting the processed information wirelessly.
- They comprise sensors, a radio frequency (RF) transceiver and a processing unit and are integrated into wearable structures such as shoes, clothes, badges and bracelets, as shown in Fig. 1

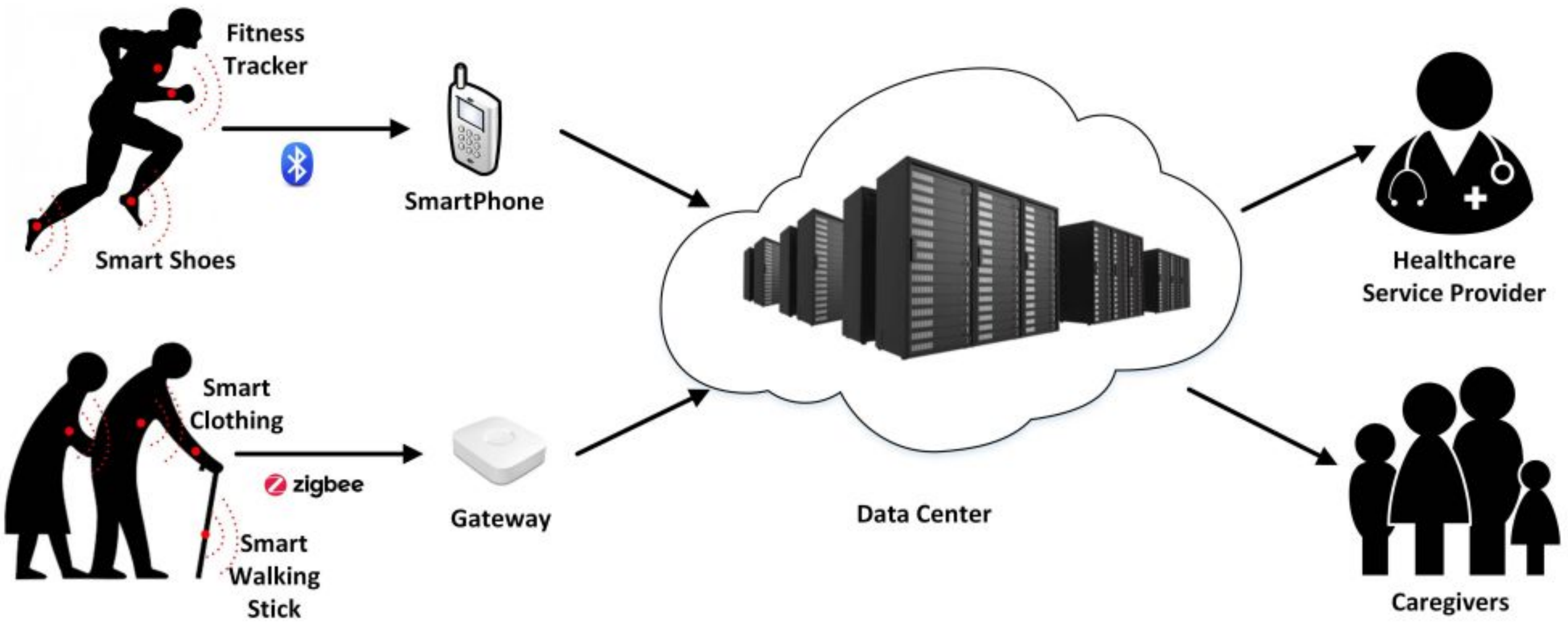


Fig. 1. Typical architecture of a wireless body area network.

These devices can be categorized as invasive or non-invasive depending on their placement in the human body. They are usually small and thin, capable of wireless communication and are characterized by low power consumption. Data from these devices are sent to a data center through wireless communication media so that the user can be monitored regularly either by healthcare service providers or caregivers.

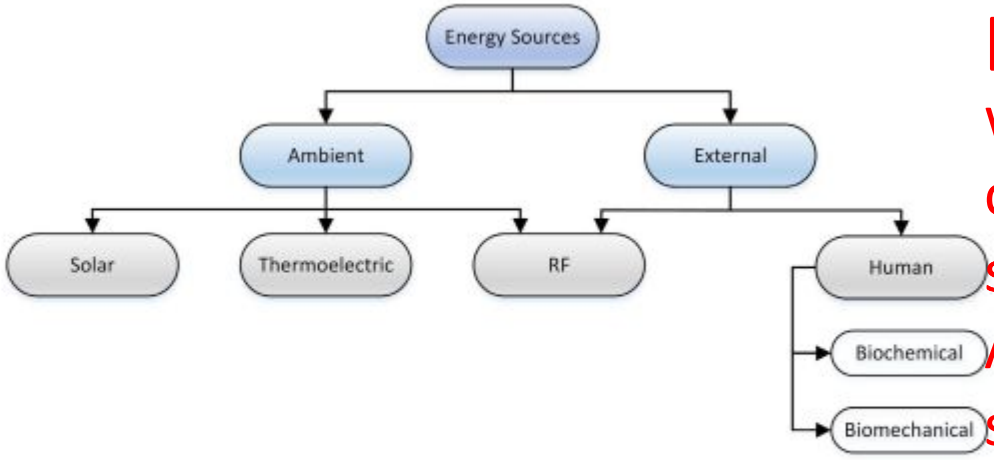


Fig. 2. Energy sources for wearable devices.

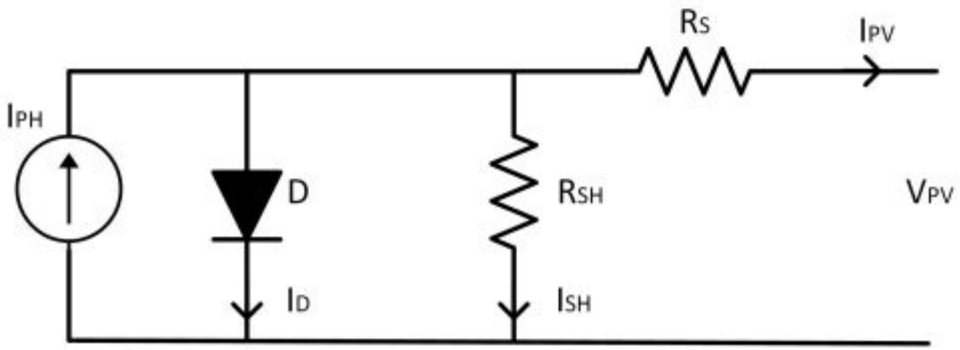


Fig. 3. Equivalent circuit of solar cell [22].

Energy harvesting can be performed sporadically to provide continuous power to wearable devices [18], [19]. The most promising sources of energy for wearable devices can be classified into two broad categories: ambient sources and external sources, as shown in Fig. 2.

Ambient sources such as Fig. 2.

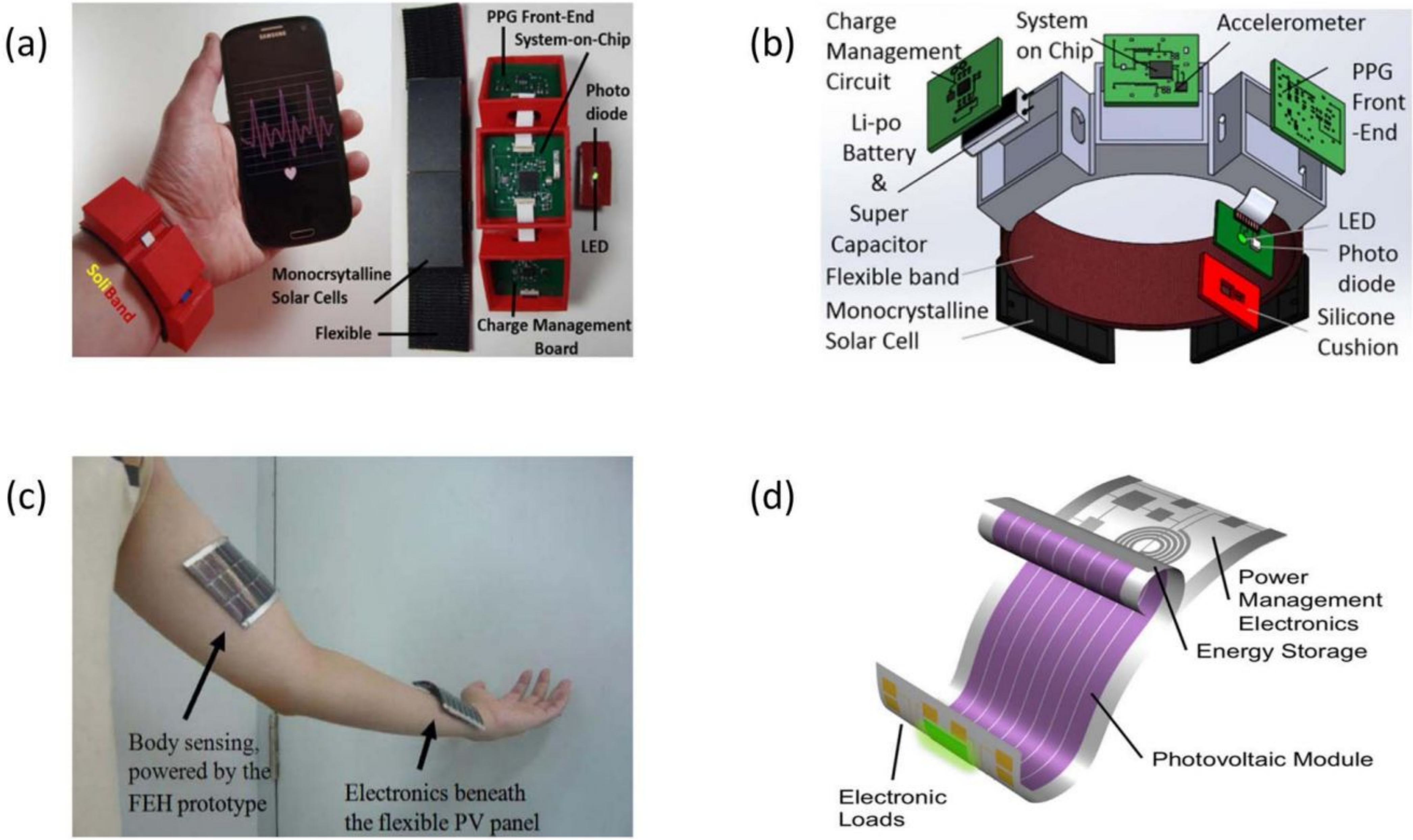
solar power, thermoelectric power and radio frequency (RF) are available in the surroundings at almost no cost

The characteristics of ambient sources are unique in terms of predictability, controllability and conversion efficiency [20].

This is because these sources may be affected by time, location and weather conditions. In contrast, external sources are predictable and controllable because they are deployed explicitly in the environment.

Solar Energy

- For several decades, solar power has been used to power consumer products such as calculators and wristwatches. It is amongst the most widespread energy sources owing to the magnitude of energy harvested. Photovoltaic (PV) cells, which are nonlinear semiconductor devices, generate electricity when the chemicals in them are exposed to solar radiation or light.
- The efficiency of solar cells depends on the material used in them. Three materials are typically used in PV cells: amorphous, monocrystalline and polycrystalline silicon. Amorphous silicon cells can be manufactured on flexible surfaces, making them suitable for wearable devices



4. (a) Integrated PV cell in Soliband [25], (b) components of device for heartbeat monitoring using integrated PV cells [25], (c) use of flexible PV for distributed biometric monitoring [26] and (d) flexible PV system [28].

Thermoelectric Energy

- The concept of using thermoelectric to power wearables is not new. Back in 1999, Seiko developed a thermoelectrically powered wrist watch that used body heat [32]. Energy can Fig. 6. System overview of a TEG-harvesting-driven wearable device [35]. be harvested from thermal sources through the thermoelectric effect by exploiting the Seebeck effect.
- According to the Seebeck effect, thermoelectric energy generators (TEGs), a property of thermoelectric materials, can be positioned on a body to convert the temperature differential T between the body skin and the ambient environment into voltage.

The voltage characteristics of a TEG are as follows:

$$\Delta V = -\alpha \Delta T \tag{3}$$

where α is the Seebeck coefficient.

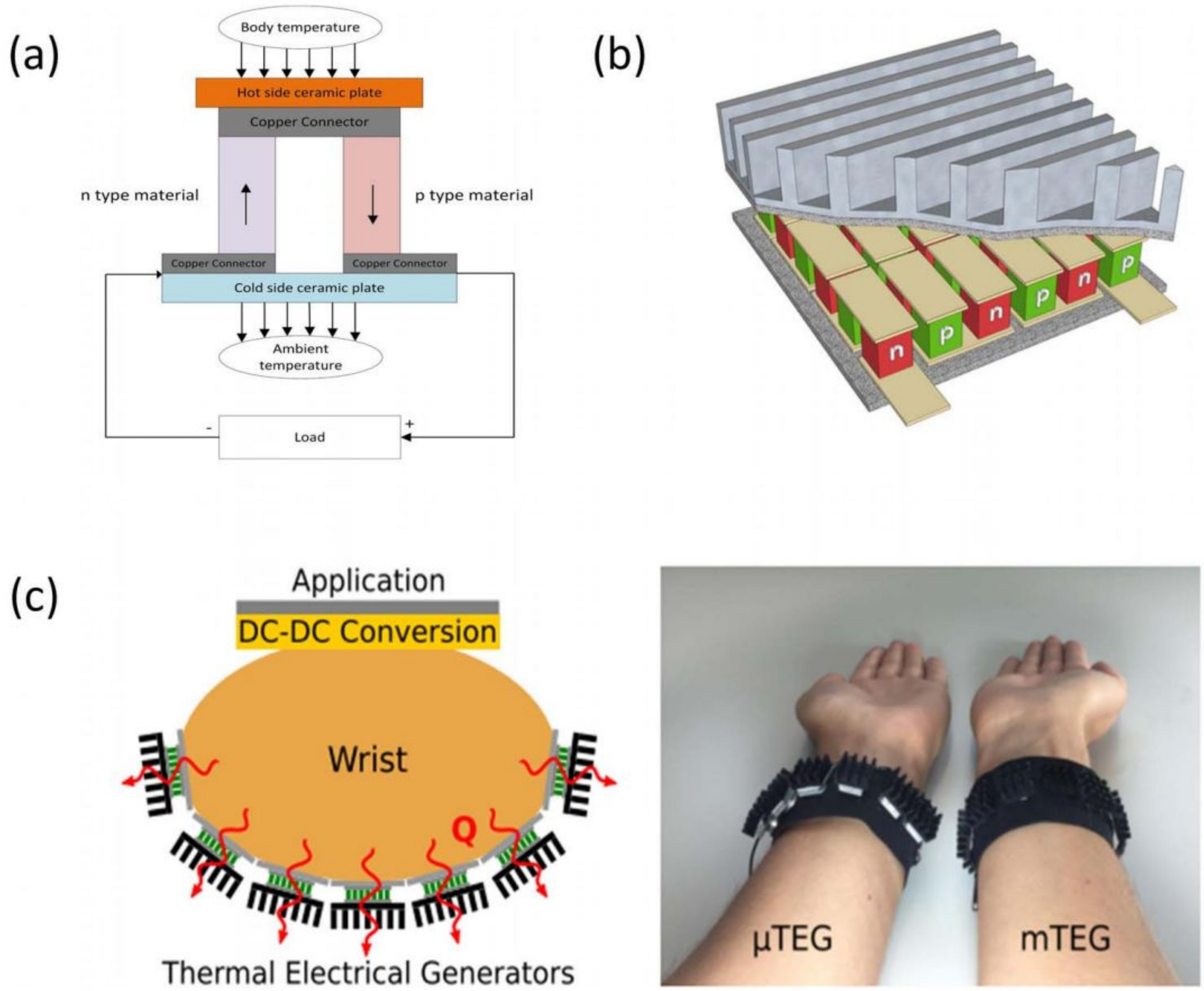


Fig. 5. (a) Thermoelectric circuitry [33], (b) typical TEG [34] and (c) TEG arrangement on a wearable device [35].

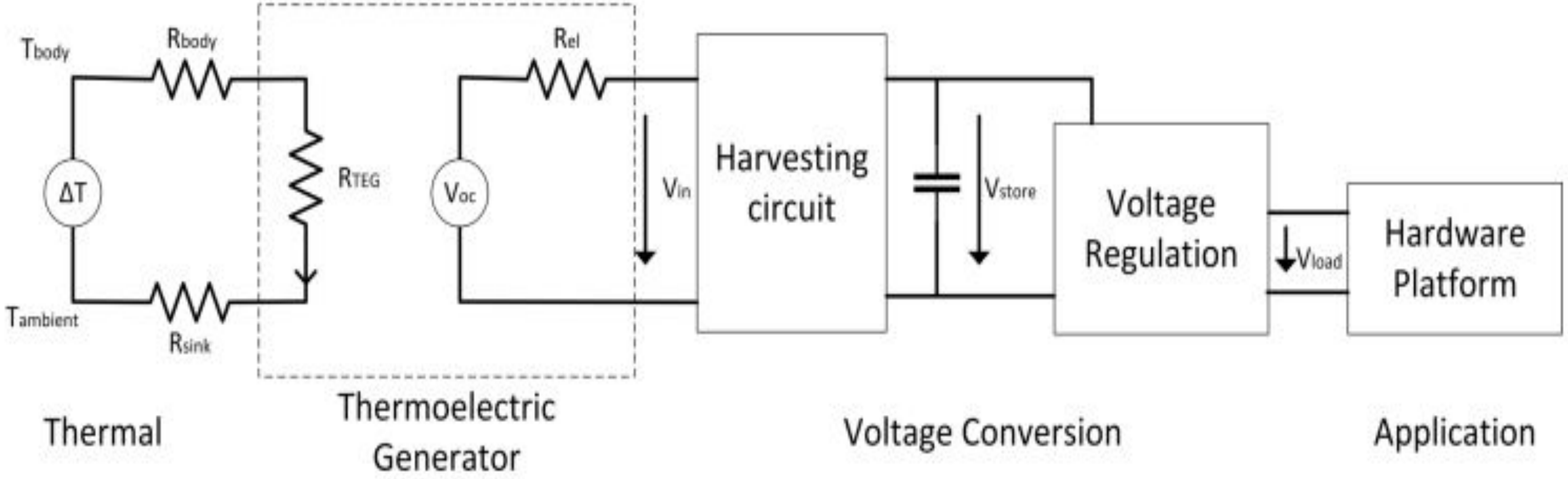


Fig. 6. System overview of a TEG-harvesting-driven wearable device [35].

Radio Frequency Energy

- Harvesting energy from radio frequency (RF) is gaining popularity because of the broad deployment of wireless technologies. Unlike other energy sources in ambient environment, RF energy can be harvested from both external and ambient sources, as shown in Fig. 7.
- Ambient RF energy is harvested from the electromagnetic waves generated by from broadcasting and wireless communication infrastructure. The power level the RF waves used for harvesting energy depends on the distance between the transmitter and the receiver. Because the distance between infrastructure units is large in rural areas compared to that in urban areas, the power level in rural area can be as low as −40 dBm.

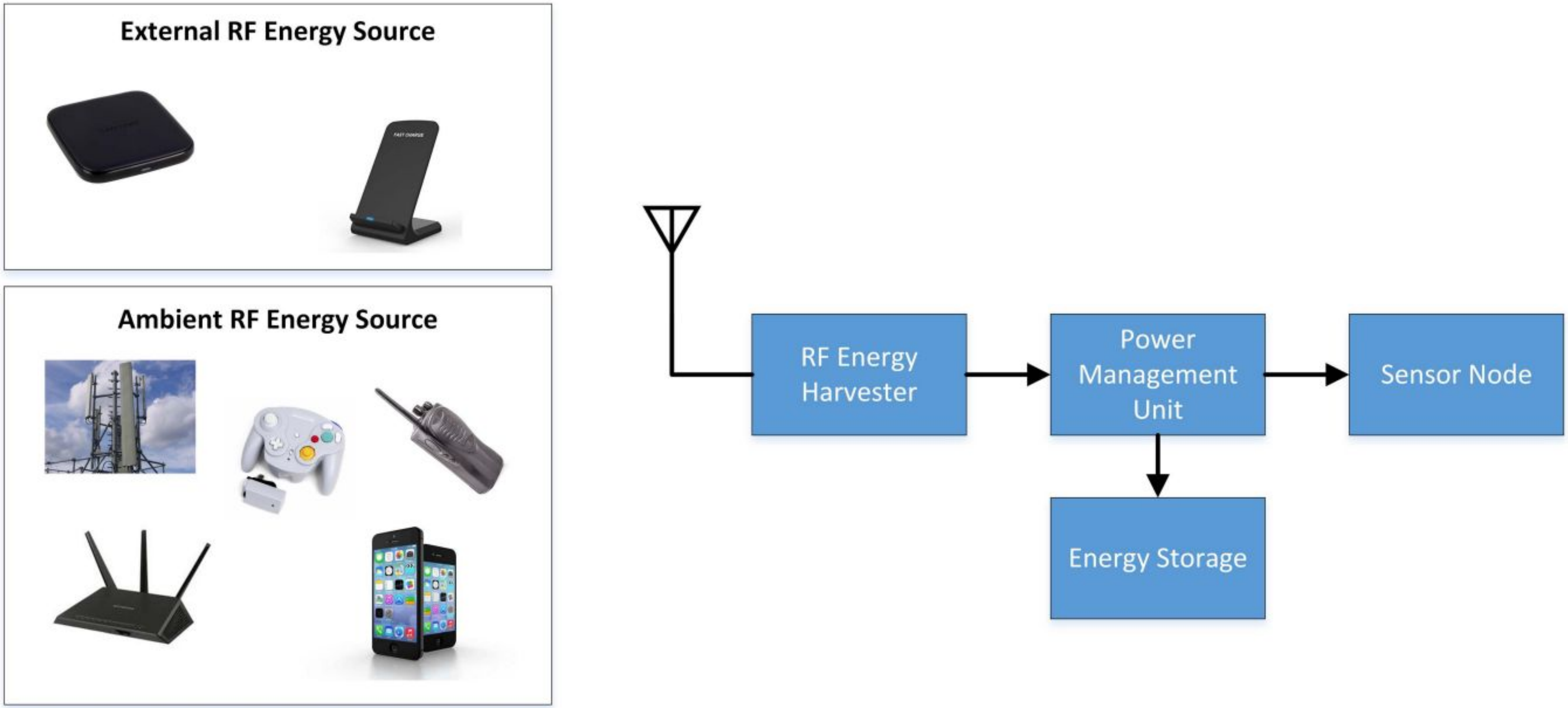


Fig. 7. General RF energy-harvesting system.

Human-Powered Energy

- In addition to ambient energy or external RF energy source, human-powered energy harvesting has attracted attention in recent years [12], [49]. The idea was conceived because human energy, which originates from food consumption, can be transformed into chemical, thermoelectric and kinetic energy.
- There is large potential for the use of human energy in wearable devices considering that human energy can provide 35–100 times more energy than a battery [50].
- In addition, the holy grail of wearable devices is to develop biological implantable devices that can monitor a user’s health without being intrusive. This can be achieved using humanpowered energy harvesters or microgenerators that convert body motions, heat, or chemical reactions into useful energy sources for wearable devices

Human-Powered Energy

- Energy harvesting from humans can be classified broadly into two categories, namely, biochemical and biomechanical. Biofluids inside the human body contain a variety of substances and active enzymes [51].
- Under certain conditions, when chemical bonds are broken, energy is released. Biochemical energy can be scavenged to provide the electrical energy needed by ultra-low-power implantable sensors, as shown in Fig. 8

Human-Powered Energy

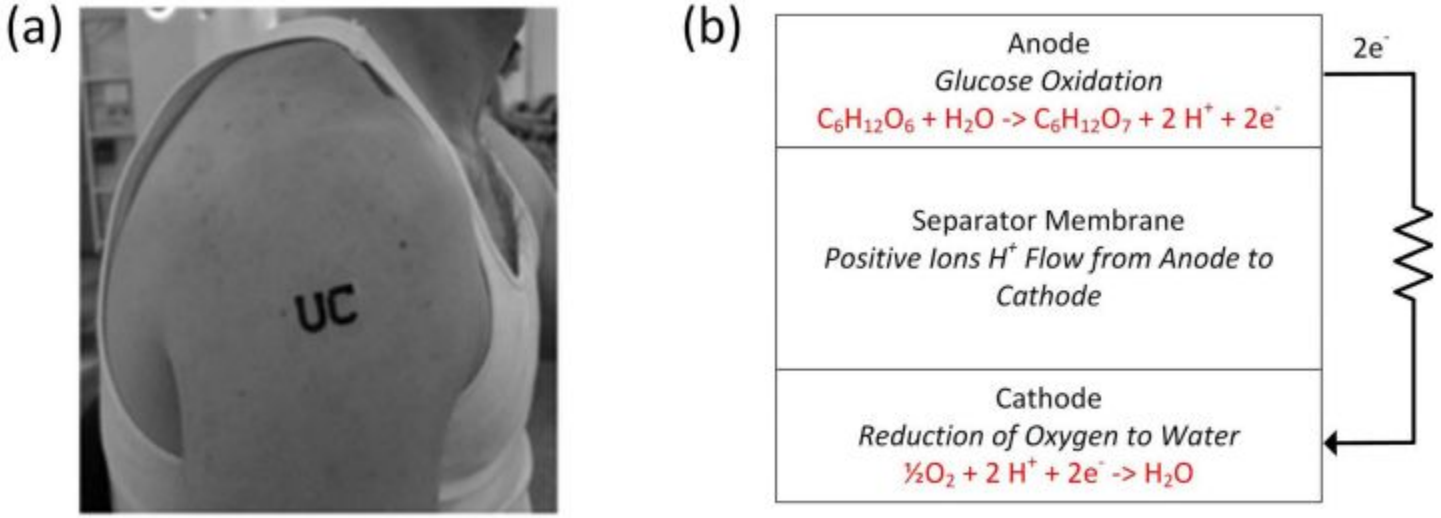


Fig. 8. (a) Noninvasive tattoo-based biofuel cell that harvests biochemical energy from lactate [54] and (b) implantable glucose fuel cell [92].

The availability of harvestable chemical sources depends on human age and human health and food intake. A key biochemical energy source is biofuel cells. In biofuel cells, power is generated via chemical reactions between the anode and the cathode and a catalyst is used to accelerate these chemical reactions. The anode oxidises a chemical compound and reduce it to the cathode. An infinite amount of energy can be harvested via this route so long as the specific chemical substances exist in the body.

Human-Powered Energy

- Glucose is one of the most common chemical substances that can be extracted from body to generate electrical energy for wearable devices. Glucose fuel cells can be classified based on the catalytic schemes used in them, namely, enzymatic, microbial and abiotic.
- Each of these catalytic schemes provides different efficiency and robustness. An enzymatic glucose fuel cell metabolizes glucose into acid and releases electrons that generate electrical energy.
- Up to 100 μW/cm2 of electrical energy can be harvested using an enzymatic glucose fuel [52], [92].
- While enzymatic glucose fuel cells can provide energy continuously, changes in temperature and pH conditions may disrupt or destruct the enzyme structure. A microbial glucose fuel cell uses living microorganisms to oxidize glucose. It can generate up to 1000 μW/cm2 of energy.

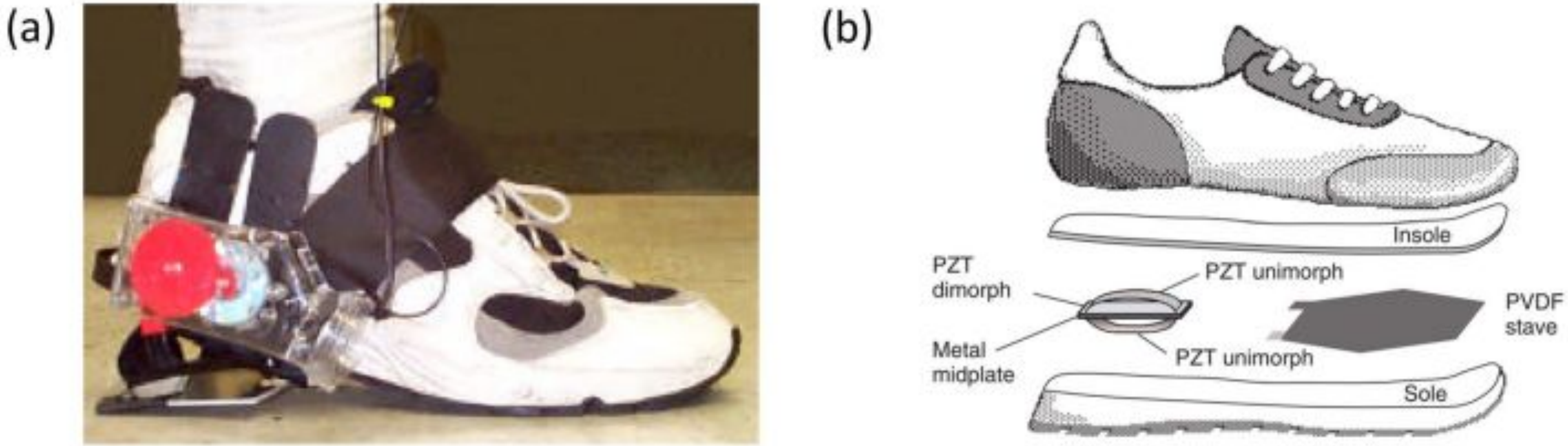


Fig. 9. (a) Simple show-mounted rotary magnetic generator [61] and (b) piezoelectric energy scavenging in shoes [62].

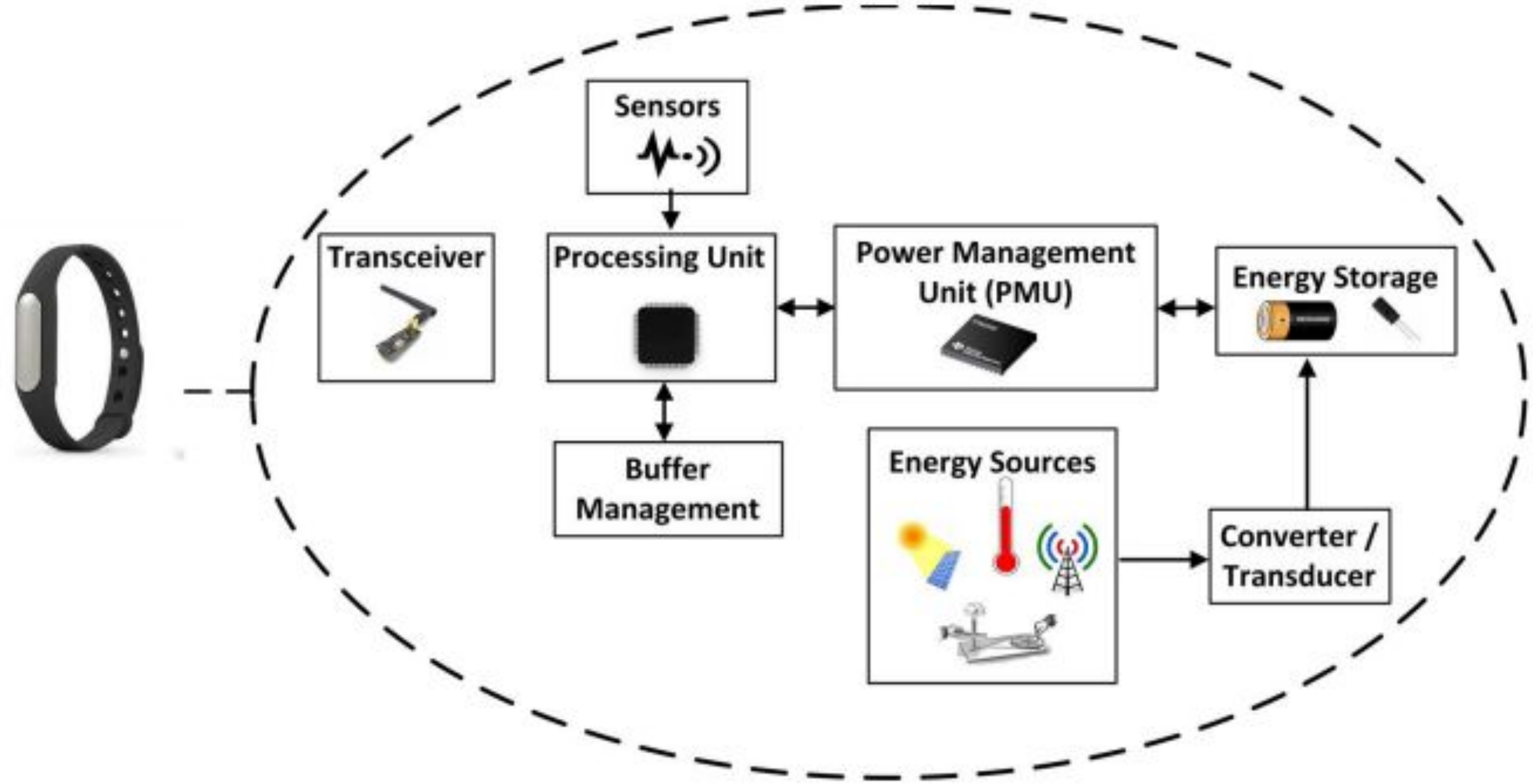


Fig. 11. Typical block diagram of energy-harvesting-enabled wearable device.