Piezoelectric Energy Harvesting for Wireless Sensor Nodes

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INTRODUCTION

Piezoelectric energy harvesting systems have received a great attention during the last decade to design self powered microelectronic devices. The concept of energy harvesting generally relates to the process of using ambient energy, which can be converted into electrical energy to meet the power requirements. The recent developments in wireless technology and ultra low power microelectronics have led to the design of self powered devices such as wireless sensor nodes. These sensors are widely used in many applications such as: structure heath monitoring, security networks, and military applications. However, these wireless sensors require their own power supply which in most cases is the conventional battery. The task of replacing the battery is impractical for remote locations or inaccessible places. For example, patients with implantable cardiac pacemaker are suffered from repeated surgeries to replace the device batteries, which is risky for elderly people life. Therefore, energy harvesting from human body can resolve this problem with the use of self powered cardiac pacemaker. In general, the piezoelectric energy harvesting system consists of: mechanical to electrical energy converter (transducer) using piezoelectric material, AC-DC converter (rectifier bridge and its smoothing circuit), DC-DC converter (power management module), and energy storage (rechargeable batteries or super-capacitors).

This article is organized as follows: a brief background for piezoelectric energy harvesting is presented, followed by a summary of self powered wireless sensor applications. Then, the international standards for vibrations and wireless sensors requirements are presented. The design considerations for energy harvesting systems are developed using morphological analysis. Finally, the conclusion and the future research directions in this field are highlighted.

BACKGROUND

Vibrations present around most machines, home appliances, and motion of biological systems are typical examples of a wasted energy that may be harvested. This source of energy is ideal for the use of piezoelectric materials, which have the ability to convert mechanical strain energy into electrical energy and vice versa (Sodano & Inman, 2005). In general, there are three mechanisms to harvest the energy from the vibrations: electrostatic, electromagnetic and piezoelectric techniques.

- Electrostatic energy harvesters produce energy from capacitance changes during the vibration cycle, where the harvested energy is derived from the work done against the electrostatic force between the plates.
- Electromagnetic energy harvesters generate energy from the induced current in coils as a result of the movement of a permanent magnet.
- Piezoelectric materials can efficiently convert mechanical strain to an electrical charge without any need to additional power (Lee, 2010; Cook-Chennault et al., 2008).

Table 1 summarizes the main comparison points between the three different techniques.

A piezoelectric energy harvester can be represented using the schematic diagram in Figure 1. The mechanical energy (e.g., applied external force or acceleration) is converted into mechanical energy in the host structure. Then, the electrical energy is produced by the use of piezoelectric material, and is finally transferred to a storage stage (Guyomar & Lallart, 2011).

Therefore, there are basic three steps in the conversion process: conversion of the input vibration energy into mechanical energy (strain), electromechanical

Table 1. Vibrations harvesting techniques

Comparison Point	Electrostatic	Electromagnetic	Piezoelectric
Application size	Suitable for MEMS applications	Suitable for macro scale applications and it has poor performance for MEMS applications	Can be used at different scales Macro, micro, and nano scales
Output impedance	Capacitive	Resistive	Capacitive
Electrical output	High voltage, Low current	High current, low voltage (Adjustable)	High voltage, Low current
Power density	Low	Medium	High

Figure 1. Schematic diagram of a piezoelectric energy harvester (Open Access: Guyomar & Lallart, 2011)
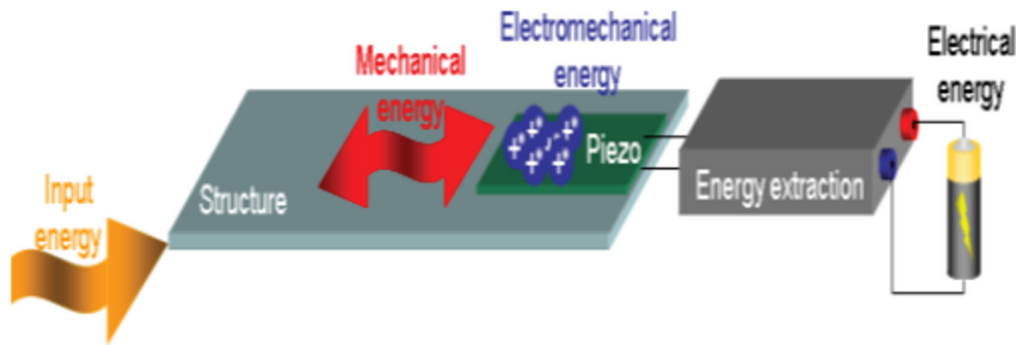
conversion (piezoelectric transducer) and electrical energy transfer. The basic components and functional blocks in a piezoelectric energy harvesting system are shown in Figure 2.

Figure 2 includes the following main components:

- **Vibration Source:** A variable amplitude and frequency.
- **Accelerometer:** Used to measure the vibration source so that the target resonant frequency and damping can be calculated and adapted.
- **Energy Harvesting Transducer:** An electro-mechanical device with a cantilever structure using a piezoelectric material. It converts the vibration energy into mechanical strain. Then, the mechanical strain is converted into electrical charges on the opposite surfaces of the piezoelectric material (Guyomar & Lallart, 2011).

- **Frequency Tuning Actuator:** This block adapts the harvester's structure to match its resonant frequency with the vibration source in order to transfer the maximum energy.
- **Power Processing Interface:** A circuit which is connected to the transducer to enable the maximum energy extraction from the transducer (*i.e.* maximum power point tracking in the DC-DC converter).
- **Electrical Energy Storage:** Required to cope with intermittency of generation and consumption. A rechargeable battery, a super-capacitor or combination of both can be used.
- **Voltage Regulation:** This is required for two reasons: the voltage on the storage element may change depending on the rate of power generation and usage (and may change a lot if the storage element is a capacitor). In addition, the electronics load may request a particular

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