Current Perspectives for Autonomous Sensor Nodes †

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Abstract: The current technological trends associated with Industry 4.0 and the Internet of Things (IoT) require an interconnected network of sensor nodes providing distributed information on the environment to enable intelligent action to be taken by control systems. Such sensors need to be wireless, self-powered and energy independent. In this work we provide an overview of possible strategies to realize a positive energy balance in autonomous sensor nodes without the use of batteries. We will first overview different sensors in terms of power consumption. We will then concentrate on energy harvesting and storage, showing state-of-the-art possibilities in both cases.

Keywords: internet of things; autonomous sensor nodes; energy harvesting; energy storage

1. Introduction

The realization of greenhouse gas (GHG) emission reduction goals is related with improving the efficiency and reliability of the industrial and transport sectors. Distributed, wireless sensor networks (WSN) are the key enablers for this task. For example, air quality monitoring can improve the efficiency of indoor air conditioning systems; vibration sensing in machines and vehicles allows predictive maintenance with consequent improved efficiency and reduction of fuel consumption. WSN need thus to be distributed in the environment, for instance being attached to building walls or fixed inside machine casings, all cases in which a wired connection is impossible, and accessibility to replace batteries is limited. Autonomous, energy-independent sensor nodes are thus necessary.

2. Autonomous Sensor Nodes

Autonomous wireless sensor nodes are composed by several elements (cf. Figure 1). The sensor itself could be a metal-oxide gas sensor, a vibration or pressure sensor, a temperature sensor, and so on. Depending on sensor type, also the power consumption of the sensor can be determined. Metal oxide gas sensors require heating up to 400 °C to function, so high power consumption can be expected [1]. Vibration or temperature sensors generally consume less power. Additionally, the ASIC (needed for power conditioning and for data collection/transmission) and the wireless module (the antenna) are power-consuming elements. In order for the sensor node to be energy autonomous, the energy supply system must be able to generate (and store) a surplus of energy between each working cycle of the sensor node.
3. Energy Supply Systems for Autonomous Sensor Nodes

The energy supply system is constituted by an energy harvester and an energy storage device. Typical energy harvesting devices are: photovoltaic cells, piezoelectric energy harvesters, thermoelectric energy harvesters, and triboelectric energy harvesters. The main requirement for the energy harvester is that the produced power is in excess of the consumed one, but the harvesting strategy depends much on the sensor’s location and boundary conditions. For example, a photovoltaic cell is not suitable for embedded applications where no light is available; triboelectric harvesters are more efficient than piezoelectric ones for low-frequency applications [2].

Energy storage elements, on the other hand, need to be able to quickly charge/discharge since the harvested energy source has high variability (e.g., wind, solar light). They need also to supply power during long unavailability periods of the energy source (e.g., during the night). They need thus to combine high power density with high energy density. From the Ragone plot (Figure 2) it is clear that no such device exists. That is, a combination of devices (e.g., a capacitor with a battery) or improved devices (e.g., a capacitor or supercapacitor with high energy density) are the way to go.

In this work, we will present a few promising strategies for supplying energy to autonomous sensor nodes, including piezoelectric and triboelectric energy harvesters, high energy density capacitors, and solid-state batteries.

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