ABSTRACT

Small embedded systems operating in unattended conditions do need to be perpetually powered if a truly pervasive paradigm is envisaged. Harvesting energy from the surrounding environment seems to be the best option. For that, a set of systems has been proposed featuring interesting solutions but not yet capable of overcoming some issues like performance and flexibility. The authors propose a novel design for an environmental energy harvesting power supply that not only can work with multiple energy sources but also can extract the maximum possible energy from them. Additionally, it can provide important information concerning the energy resources of the system. Focusing particularly on the system’s design, the authors present results from a reference implementation that highlight the low wasted power and high efficiency characteristics of the system.

Keywords: Embedded Systems, Energy Harvesting, Environmental Energy, Maximum Power Point Tracking, Sensor Networks

INTRODUCTION

Small embedded systems do often have to face energy constraints, preventing them to ensure the lifetime required for many applications. Even using hardware and software specially devised to reduce their energy consumption, the small form-factor batteries that equip such systems are incapable of assuring a perpetual operation. Indeed, when unattended operation for long periods or deployment in inaccessible places is required there is a need for a permanent power supply solution. In such cases, harvesting energy from the surrounding environment is the practical way to permanently power these embedded devices.

Wireless Sensor Networks (WSN), a paradigm in this field, can greatly benefit from environmental energy harvesting. In fact, “to instrument the physical world with pervasive...
networks of sensor-rich, embedded computation” (Estrin, 2002), a method for permanently powering the network nodes is required. Scavenging energy from the surrounding environment is a fundamental step towards truly pervasive sensing applications as there is no need to periodically replace node’s batteries, making the systems energetically autonomous.

State-of-the-Art WSN platforms typically require as much as 80 mW of continuous power. However, as these systems are usually designed for interrupt operation with typical duty cycles in the range of 1-5% (Dubois-Ferriere, 2006; Buettner, 2006), one can estimate an average power consumption of tens of mW.

While innumerable types of ambient energies do exist, only a few can be recovered with good efficiency. In outdoor settings the most common source of environmental energy is the Sun; even in some indoor scenarios it is possible to use solar energy for low-power applications.

Solar energy can be harvested using photovoltaic solar panels. The power density of solar panels, in outdoor situations, is around 15 mW/cm² while in indoor situations it is much smaller, typically around 6 μW/cm² (Roundy, 2003).

Due to the limitations of photovoltaic systems in indoor applications, the use of mechanical energy is sometimes preferred, especially if a consistent source of vibrations is easily available (machines, structures, wind, etc.). The mechanical energy from vibrations can be extracted by different transducer mechanisms: piezoelectric (Roundy, 2003), electromagnetic (Khaligh, 2010), electrostatic (Roundy, 2003), etc. The power density of these devices is around 200 μW/cm³ (Roundy, 2003).

Of course this environmental energy must be stored when not immediately needed; for this, energy storage devices are required. The most common way of storing in excess energy is through the use of rechargeable batteries. Lithium Ion batteries are the most popular since they: i) have no memory effect, ii) have a high energy density, iii) feature a low self-discharge rate and iv) support a relatively high number of recharging cycles. The last factor is crucial in the design of a power supply intended for perpetual operation as the one discussed herewith, since rechargeable batteries do have a limited number of charge cycles, rendering a lifetime of a couple of years on a daily basis (Jiang, 2005), if they are not smart charged.

In spite of their small energy density, ultracapacitors are a good alternative to rechargeable batteries because they are easier to charge, support a higher charging/discharging current, and present a number of life cycles theoretically infinite.

Several power supply solutions, recovering energy from the surrounding environment, were developed in the last years with the purpose of permanently powering small embedded systems. These solutions can be usually classified in two different groups: i) integrated circuit approaches, e.g. (Tsui, 2006; Le, 2008; Shao, 2009), usually conceived for handling very low power sources, and ii) discrete systems, e.g. (Jiang, 2005; Simjee, 2008; Park, 2006), typically designed for fulfilling much larger power requirements.

The former are characterized by very small power handling, incompatible with the aforementioned WSN requirements and lacking energy buffering so much needed for sensor application due to their unpredictable/periodic behavior, in most cases. Moreover, they do not feature a smart management of the sources power availability as well as its storage.

The latter are frequently designed specifically for a given platform being, in some cases, fully integrated with it and lacking as such the required generality to be used elsewhere. Another disadvantage of some of this kind of systems relates to the difficulty of accommodating multiple energy sources restricting them to be used solely in certain scenarios, particularly outdoors. Finally, the use of just one energy storage device and a rigid analog control, without the sufficient flexibility to take the maximum advantage of transducer devices in a wide range of operating conditions, imposes limitations difficult to overcome with such architectures. This situation opens space for innovative energy
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