Abstract

Autonomous sensors (AS) are wireless measurement units comprising sensors and signal conditioners, a processor, a transceiver, and a power supply. To save power, they usually remain in *sleep mode* and only *wake up* to perform their indicated function. The field of AS has been driven by the emergence of wireless communication standards combined with reduced power consumption, costs, and size of the electronic devices. Nonetheless, long-term deployment of AS demands further advances in their power supplies and power management.

Currently, there are two methods for powering AS: primary batteries and energy harvesting. In this thesis we provide an integral approach to the power supply of low-power AS that encompasses batteries, storage units and energy harvesters. We propose circuits and methods for efficient energy and power management. We focus on energy harvesting, with optical and (deliberately radiated) radiofrequency (RF) energy. Optical energy features high energy density, especially outdoors. Alternatively, RF remote powering can be the sole option for AS embedded in soil or within a structure.

Firstly, we assessed the power consumption of AS, ultimately devising a model that considers the load (AS excluding the power supply) as a pulsed current sink. We took experimental measurements using a commercially available autonomous sensor that support this analysis. We then performed a general analysis of the ambient energy sources amenable to powering AS, and on designing the power supply subsystem based on traits such as power density and availability.

We then performed studies on primary and secondary batteries. Secondary batteries and supercapacitors can be used as storage units for harvesting energy but not as the main power source, due to their leakage or low energy density, respectively. Some batteries, especially low-capacity models, have a relatively high series resistance. When AS wake up, the voltage drops, and some power is dissipated in the battery resistance, thereby shortening the device’s lifetime. To overcome these issues, we propose the use of hybrid storage units formed by a battery in parallel with a supercapacitor. We discovered that for powering AS, supercapacitors extend the battery lifetime between 16% and 33%.

We employed a generic model for optical energy transducers (solar cells) to compute the *I-V* and *P-V* curves as well as their dependency on optical power and on temperature. Then, we considered methods and circuits for efficient energy

management based on different circuit implementation complexities. We first analyzed the performance of a direct-coupled (diode) connection leading to efficiencies between 70% and 90%. We then devised maximum power point tracking (MPPT) methods. First, implemented a new fractional open-circuit voltage (FOCV) method, which gives a tracking efficiency greater than 99.5%, which is higher than that reported for current implementations. Additionally, we devised and tested a new MPPT method that provides a tracking efficiency greater than 99.6% and an overall efficiency greater than 92% for a photovoltaic (PV) panel power greater than 100 mW. We took outdoor field measurements that reveal energy gains of roughly 10% over a direct-coupled circuit.

We analyzed the RF energy transducer (antenna) for its use in AS. Based on circuits proposed in the literature, we performed extensive simulations for several incoming power levels at the antenna (from -10 dBm to 10 dBm). For the antenna, we considered a voltage source with an output impedance of 300 Ω, and then used a matching network based on a shunt inductor. We determined that circuit efficiency slightly depends on the number of stages used for the voltage rectifier multiplier, but varies widely with the received power (ranging 10% at -10 dBm to 80% at 10 dBm). We plotted efficiency versus the output voltage of the rectifier at several power levels and at numerous stages of the circuit rectifier: as the power level increases, so does the output voltage corresponding to maximum efficiency. We performed additional simulations with a 50 Ω antenna and an *LC* matching network, reporting better results at low levels of incoming power (0 dBm, -10 dBm). Lastly, we did experimental tests with a folded dipole antenna (about 300 Ω), shunt inductor matching, a three-stage rectifier and a storage unit composed of two series connected NiMH batteries.

Keywords

Autonomous sensors; primary and secondary batteries; supercapacitors; hybrid storage units; energy harvesting; solar cells; maximum power point tracking (MPPT); and radiofrequency (RF) harvesting.