Design and Power Management of Energy Harvesting Embedded Systems

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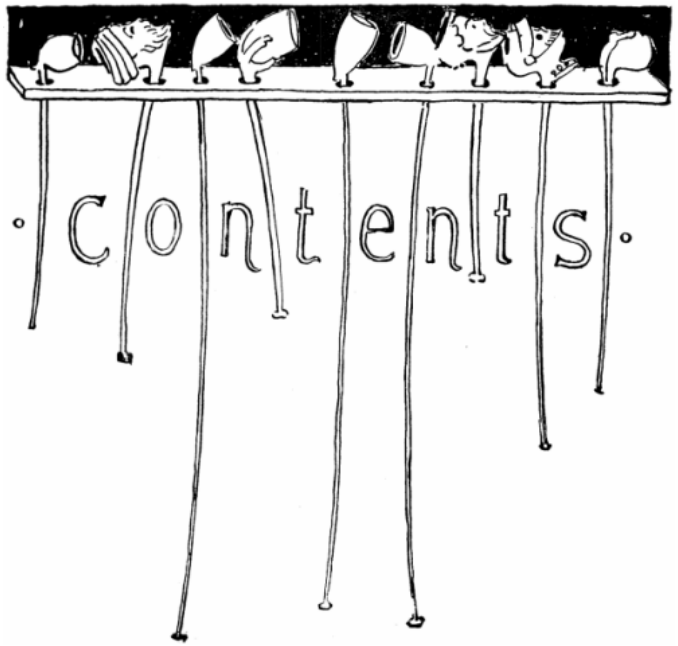
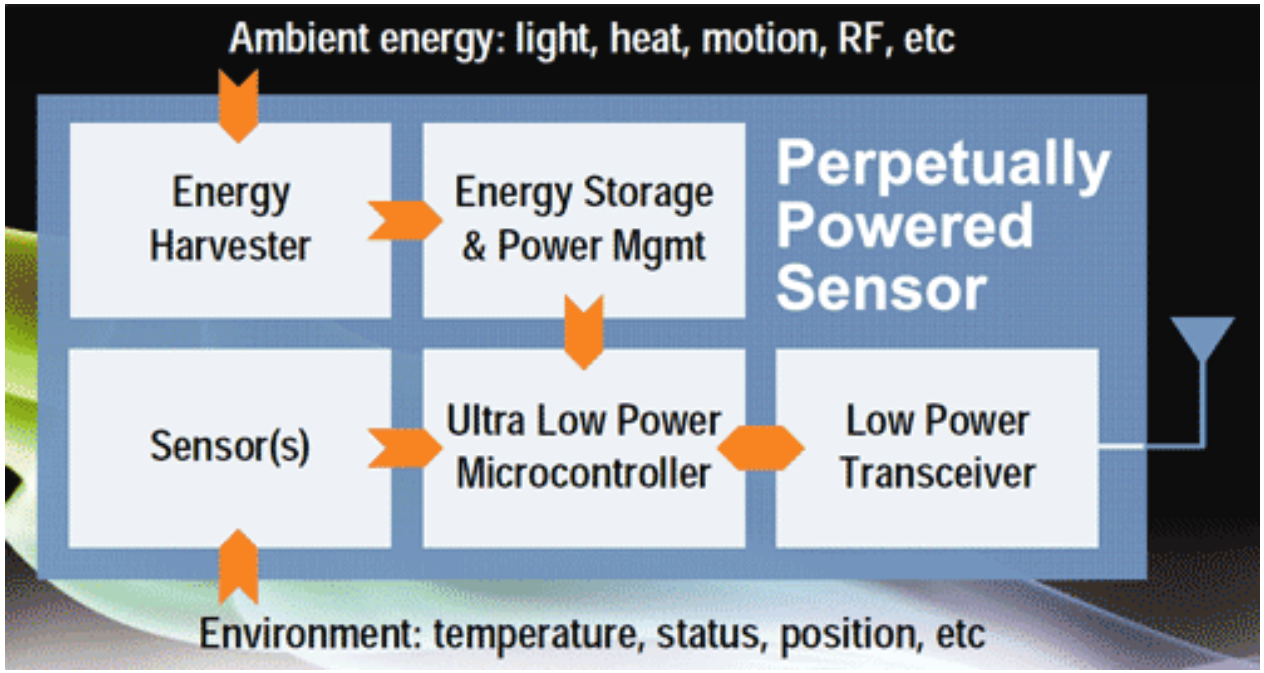
The Contents



- Introduction about energy harvesting devices
- System design issues
- Power management related issues

Energy Harvesting System - WSN

- Harvester
- Storage Device
- Sensor Node



System Design Issues

1. Voltage and Current

- Without high enough voltage, it is difficult or impossible to either power the system directly or to charge an energy storage device
- Voltage regulators are used to bridge the gap between the supply and the consumer.
- Linear and switching regulators
- Switching regulators – Buck, Boost and Buck-Boost
- Power efficiency and energy efficiency are different

System Design Issues

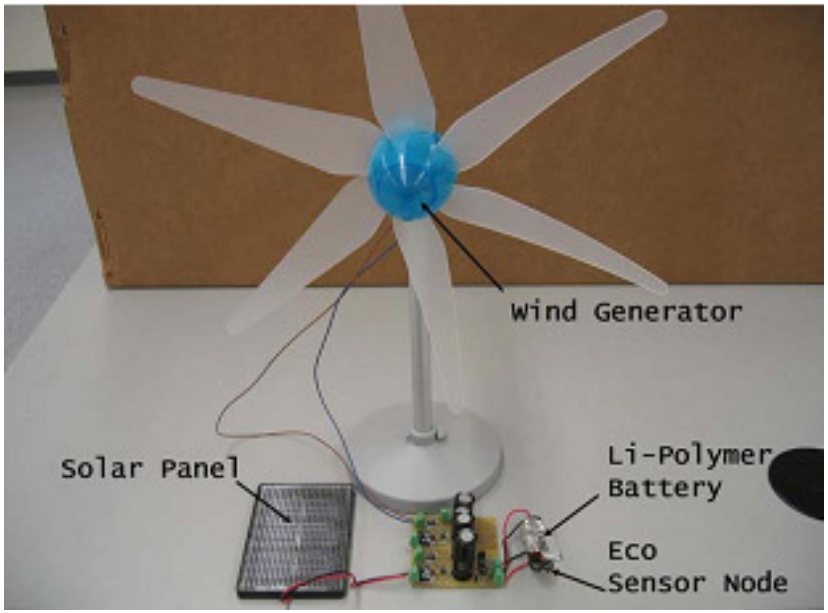
2. Maximum Power Point Tracking(MPPT)

- Occurs when supply and load are impedance matched
- The input intensity can be determined by measurement either before or after conversion to electricity.
- The control for MPPT can be implemented either in hardware or software
- Hardware control – simple, low overhead but tend to track MPP with a hysteresis band
- Software control – Use precious I/O pins and overhead is more due to use of DSP

System Design Issues

3. Power deframentation

- One problem with harvesting energy from environmental sources is the wide dynamic range of power.
- Even with MPPT, the available power may be so low that it is below the useful threshold.
- To solve this problem, one may wish to harvest energy from multiple sources.



System Design Issues

4. Energy Storage devices

- Rechargeable Battery – low leakage but limited charge cycles
- Supercapacitors – infinite charge cycle but more leakage but it is less of a problem if energy is replenished frequently
- Hybrid
- The combination of MPPT using supercapacitors poses new challenges

Power Management Issues

1. Energy Neutrality in Harvesting Systems

- Conventional energy optimization metrics might not be suitable in an energy harvesting scenario.
- The objective in a battery-powered sensor networks is to maximize network lifetime under a total energy constraint.
- This changes if energy harvesting is allowed since the amount of energy available itself depends on the time duration for which the system operates.
- A more relevant design objective might be to operate in an energy neutral mode, consuming only as much energy as harvested.

Power Management Issues

1. Energy Neutrality (continued)

- Theorem - Model of the power generated by the harvester:

$$\rho T - \sigma_2 \leq \int_t^{t+T} P(t)dt \leq \rho T + \sigma_1$$

$P_s(t)$ – Power output

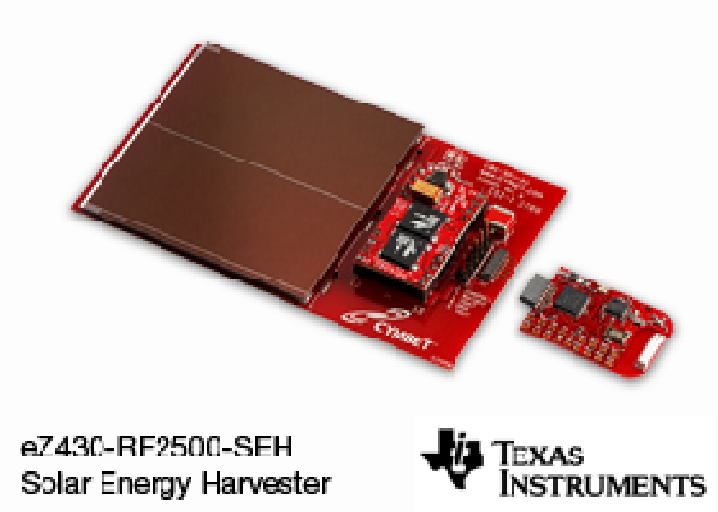
ρ – rate at which energy is available from the transducer

σ_1, σ_2 – the burstiness caused by temporal variations is bounded by σ_1 and σ_2.

Power Management Issues

2. Node Level Power Management

- Power management at runtime
- An algorithm for harvesting-aware duty cycling of wireless sensor nodes.
- Dynamic voltage scaling.
- Determining the optimal duty cycle for a node using Exponentially Weighted Moving-Average (EWMA) filter based prediction model.



Power Management Issue

3. Network Level Power Management

- Power management considering the whole network.
- Energy aware routing protocols in sensor networks typically use battery energy based routing cost metrics.
- But only battery awareness is not sufficient to select the best routes.
- Hence an enhanced routing cost metric that considers both the harvesting potential of a node as well as its residual battery level is needed.

So, what is the conclusion ?

- Active research on Energy Harvesting Devices
- Energy harvesting embedded systems have a brand new class of applications
- The power consumption has been reduced to the same level as the harvesting devices are capable of outputting.
- But, it seems unlikely that existing systems can automatically operate efficiently by just adding an energy harvesting module.
- In order to operate efficiently the entire system must be optimized in a holistic way from the design of the architecture to power management at the application and networking levels.

Questions and comments