Rapid Control Prototyping for Energy Management of Self-powering Sensors and Embedded Cyber Physical Systems

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Summary: This work shows the structure of an advanced methodology for designing energy management related parts of cyber physical systems following the established method of rapid control prototyping. This methodology is implemented in a toolbox and applied to a scenario in the area of personal sensing devices. Especially when using sensors not only for measuring purposes, but also for energy harvesting, low energy availability has to be considered.

Keywords: Energy Management, Embedded Systems, Cyber Physical Systems, Rapid Control Prototyping, Sensorial Materials.

1. Introduction

Combining sensor principles with the ability to harvest energy is an emerging technology in the field of material sciences. It gains even more significance in the context of embedded and cyber physical systems. In the human environment the approach of the project "Guardian Angels" is about to be discussed and chosen one of the candidates of Future Emerging Technologies having a major technological influence in the next decade. This is also reflected by the initiative "Industrie4.0" by the German Academy of Technology (acatech).

Especially when using sensors not only for measuring purposes, but also for energy harvesting, low energy availability has to be considered. Though, in the world of smart materials special problems need to be addressed:

1. Sensor signal processing and error detection
2. Energy supply with appropriate management
3. Communication infrastructure and algorithmic data reduction

This work introduces well known development schemes from the field of automation and control to a smaller scale. This article gives an overview about existing modern development schemes like Rapid Control Prototyping and their application in embedded sensor systems. The back-ground of self-powered sensor system is presented to show the specific requirements of such systems.

Self-powered systems require new soft- and hardware approaches for Rapid Control Prototyping. An estimation of power consumption as well as an energy awareness to control the system depending on the energy supply and demand is the core basis for this. Energy management has to be tailored to the duties of the sensor. Therefore simulation is a key to the development of successful long lasting embedded systems.

The outlook for this work described here will be to develop further the code generation feature of today's tools. Special low consumption design could be the basis for next generation embedded sensor systems. This offers the opportunity to use embedded sensor clouds and cyber physical systems with the durability of a products life-time.

2. Basic Technologies

2.1 Cyber-Physical Systems

From today's point of view embedded systems will be connected on different levels of networks. When embedded systems are an integral part of the material such as sensorial materials the functionality of smart products will be influenced by the software and the network. This follows the definition of cyber physical systems.

2.2 Basic Elements of self-powered Sensor Nodes

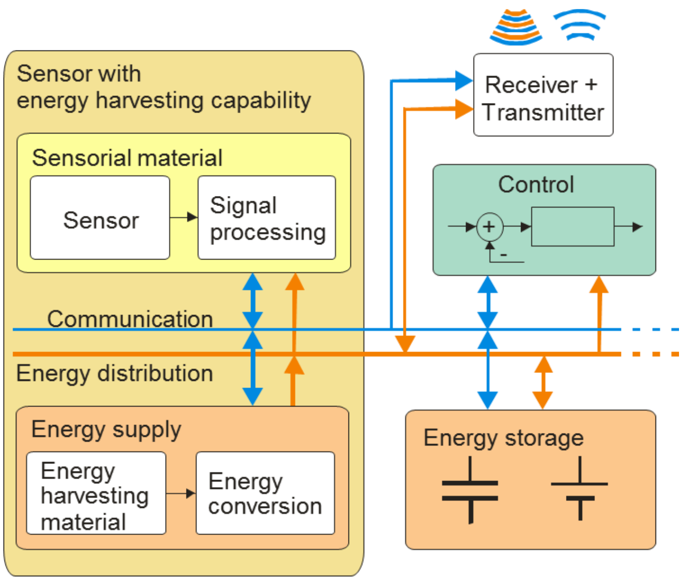

Figure 1. Overview sensor node.

In the context of this paper sensorial abilities should be structured in a single sensor node. A sensor node could serve one or more measurements and could be supplied by single or multiple sources.

Sensor nodes could be implemented according to [1]. The model of a sensor node can be divided into the parts data (acquisition, processing and communication) and energy (supply, storage, consume). Though the research activities also focus the optimisation of data processing and communication in respect to the energy consumption, this paper will concentrate on modelling, simulation and analysis of the energy branch.

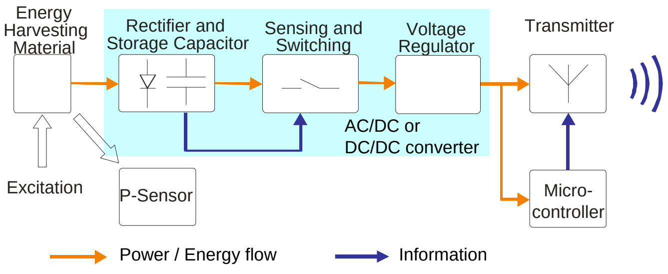

Figure 2. Example for a radio based sensor node with material for energy harvesting and sensing.

For most self-powered applications the energy provided by the energy harvesting device has to get converted. In [1] a more detailed view into a power system of a sensor node is displayed. Power flow from the exited harvester is converted to higher voltage levels. Typical is a small capacitor to buffer energy. When a certain voltage level is reached the next circuit activates the main functions of the sensor node. A voltage regulator is used to provide constant conditions for the parts of the node like measurement unit, processor/micro controller and if needed a radio transmitter.

2.3. Rapid Control Prototyping

In the field of control design a simulation based method for implementation and testing has been well established. Transferring this technology to the sector of cyber physical systems offers the generation of energy aware algorithms for sensorial materials. Future abilities imply the generation of program code or application specific hardware blocks (see Figure 3) [1].

3. Tool for Simulation and Development of Energy independent Systems

The structure of the toolbox is oriented on the node scheme according Figure 1 and is ordered from the energy's point of view (Figure 4).

For each element there are generic blocks in the structure to cover the main functionality. Special parts can be derived and added to the Library.

According to the naming conventions in Matlab/Simulink an input signal is connected to an "inport" and the output of a block is fed through the "outport". A mask in Simulink can be provided as a GUI for setting parameter values comfortably, which then are connected to constant values inside the block model implemented in Simulink. [3]

All blocks of the energy toolbox are masked for convenience e.g. to parameterize the block according to the data sheet.

In the next chapters some example implementations are described to learn to know the basic structure of the toolbox and allow the reader to follow the application scenario in the next chapter easily.

4. Applications

- condition health monitoring of large constructions (bridges) [2]
- collisions of robot construction with the environment
  - providing bulk material with sensor nodes
  - sensing organ on the surface
  - for detecting approximations
- carbon fiber-reinforced polymer CFRP
  - fulltime shock monitoring of large area
- wind turbine blade
  - full observation of stresses
  - monitor sensor node inside the blade

5. Example

To show the usage of the toolbox a simple scenario is chosen to elucidate the work flow of the analysis. The scenario is simplistic enough to calculate the result by hand, but it shows that someone not being an energy expert can figure out his own application scenario. After the main principles and components have been fixed it is much easier to specify the electric circuit and the data processing on a micro controller. Therefore the

Energy Sources
- + Batteries
- + Ideal Sources
- + Inductive/Magnetic
- + Mechanical
- + Piezo Electric
- + Photo Electric
- + Thermal Electric
- + Transformators

Energy Converters
- + AC/DC
- + DC/DC
- + Voltage Regulators
- + PWM
- + Amplifier

Energy Storage
- + Accumulators
- + Capacitors

Energy Consumers
- + Actuators
- + Microcontrollers
- + Sensors
- + Radio Modules
- + Illuminants

Figure 4. Structure of toolbox

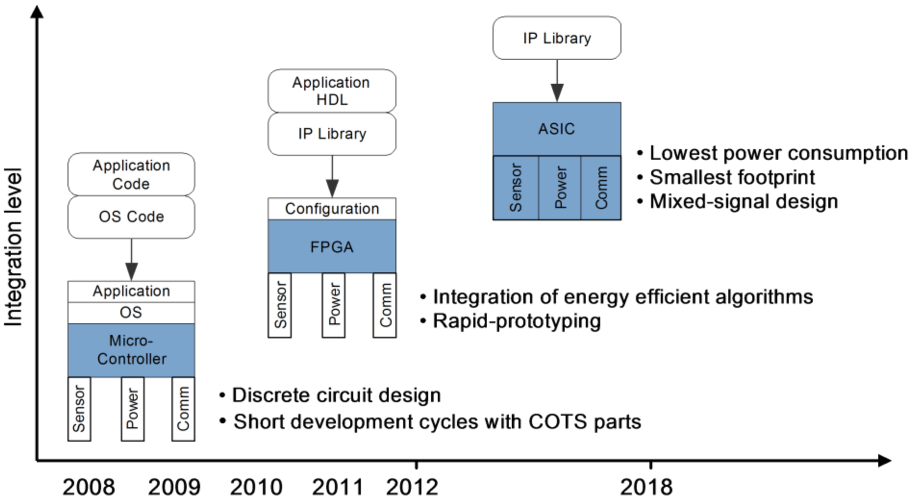

Figure 3. Roadmap for integration level of sensorial material.

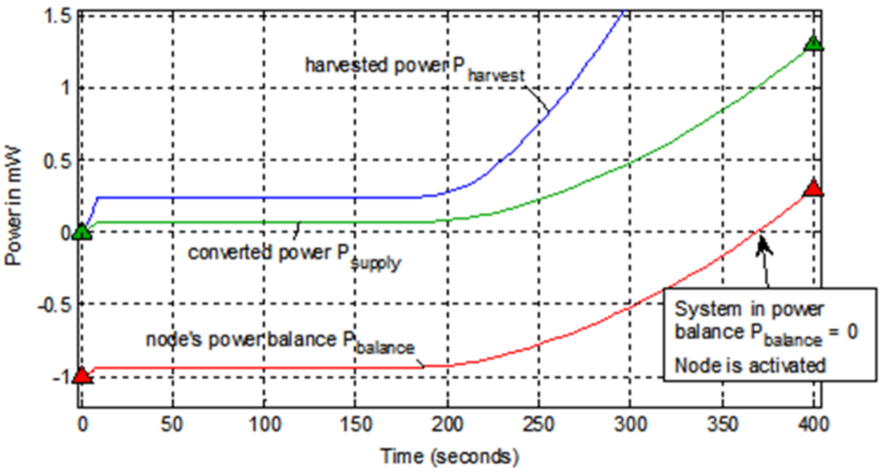

Figure 5. Power balance.

measuring systems designer can concentrate on measuring and evaluation.

The proposed scenario is derived from former research activities on supporting emergency management [4] by adding telemetric features to the equipment of fire fighters [5]. It is not carried out within a real implementation, yet.

The main idea is to provide sensing capabilities to a jacket of a fire fighter. The sensing capabilities should not rely on battery power because it should work maintenance-free.

A sensor node configuration according to Figure 2 is used. There are 12 thermal generators sourcing a DC/DC-Converter with 30% efficiency. For the other devices the consumed power is set according the dada sheet: temperature sensor (7.5 µW), measuring circuit (0.4 mW), microcontroller (0.5 mW) and radio transmitter (0.1 mW) (see Figure 6).

The power balance in Figure 5 reaches the level of operation when generated power $P > 0$ mW at $t = 370$ s. There is the Temperature difference around 20°C. This is giving 80 s of warning time till the temperature inside the jacket is rising rapidly at $t = 450$ s (Figure 5). Thus the fire fighter gains additional 80 s of time while strategic withdraw is safe.

Actually fire departments sometimes decide not to use these protective jackets, because of the un-expected behaviour in temperature rise. Sensor nodes like the described system are maintenance-free and can contribute to assist the fire fighters to avoid personal hazards.

6. Conclusions

The toolbox is now capable to simulate and demonstrate simple scenarios for the parameterisation of self-powered sensor nodes. It is a tool for a measurement systems designer outlining new scenarios for measurement applications. Therefore the usage of the toolbox is kept simple and generic. For a full simulation of e.g. the electric circuit (Spice) or communication issues over wide spread wireless sensor networks other tools are more powerful and accurate. But these tools are limited to a defined hardware or require an exact specification. This toolbox can contribute to the process of defining them and figuring out the right hardware configuration. The focus on energy harvesting principles enables the process of exploring the area of self-powered sensors and sensorial material.

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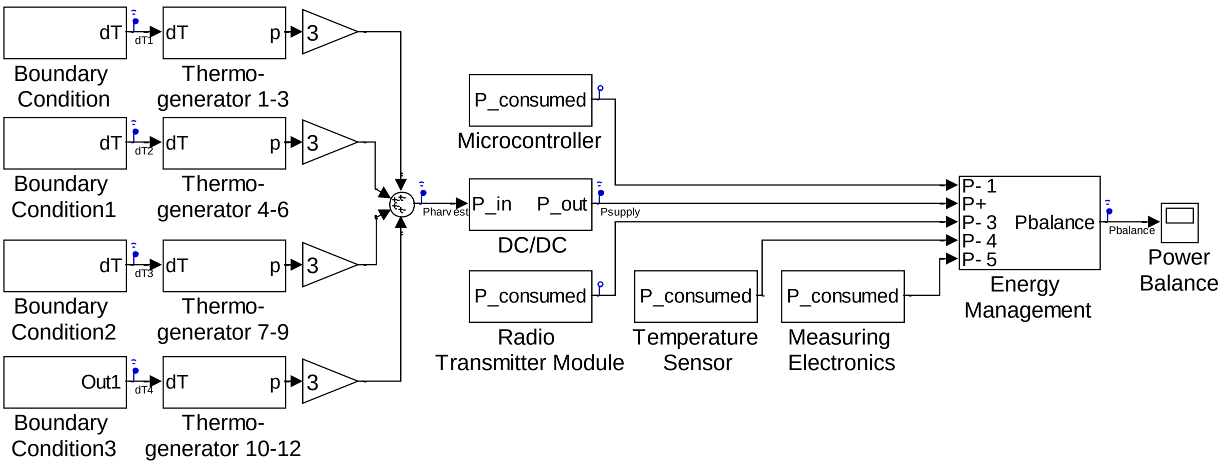

Figure 6. Power model of a thermal activated temperature alert embedded in a thermo isolating jacket for fire fighters.