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Decision support method for the design of embedded energy in autonomous microsystems

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ABSTRACT

We propose a decision support method in embodiment design, dedicated to embedded autonomous microsystems design. The main objective of our work is to go beyond battery configurations by supporting the design of autonomous microsystems, namely systems able to harvest and use available energy from their environment. The main challenge of our approach consists of supporting the designer's decisions from qualitative representation to physical models. We have thus developed instruments, both based on flows and effect analysis and behavioral component modeling. The method decreases the number of potential alternatives to obtain the best solution and the associated models. To validate our method, we focus on a marketed wired road sensor.

1. Introduction

Nowadays products have more and more functionalities and have to be autonomous to be used in a wide range of fields like the car industry, aeronautics and medical applications. Cars, aircraft and human bodies are complex energy environments where microsystems may find and harvest many different sources of energy.

The aim of our work is to support the design of autonomous microsystems powered by the energy that is available in their environment (also called ambient energy). Therefore, we propose a decision support method whose goal is to select sources and the energy systems that extract, convert and transport energy to the application.

The first difficulty in the embodiment design process derives from the fact that our method must be supported by physical models and lead to quantitative data, starting from a qualitative definition of the product's characteristics. The second difficulty stems from the alternatives in the energy sources selection and the system that guarantees the application is power supplied.

To guide designers, we have thus based our method on the identification, analysis, modeling and characterization of functional and antagonist flows and effects.

After explaining the specificities of embedded autonomous microsystems and the key features of our method, we illustrate it through an application case related to the energy supply of embedded autonomous sensors in the ground.

2. Design problem analysis

2.1. Embedded autonomous microsystems

A microsystem is defined as a miniaturized intelligent system integrating sensors and/or actuators associated with a processing unit (Dupé & Briand, 2010). Microsystems interact with their environment by means of sensors and actuators, and communicate with a remote control station or other microsystems that are present in their close environment (Hitachi, 2003; Rabaey et al., 2000).

Moreover, microsystems require an energy source to work. Most of the time, they are powered with batteries which limit their lifetime. Extending this lifetime is particularly interesting in systems with limited accessibility like embedded microsystems. Such devices evolve in environments where numerous energy sources are available. As a result, we can think about harvesting energy sources that differ from the one commonly used in other systems.

Energy harvesting is achievable with microsystems having very low power consumption (Gilbert & Balouchi, 2008; Roundy et al., 2004a). It is defined as the conversion of ambient energy into exploitable electrical energy. When compared with the energy stored in batteries, the environment represents a relatively unlimited source of energy. This energy can be harvested from different sources including sunlight (Jiang et al., 2005), the wind (Federspiel & Chen, 2003), vibrations (Beeby et al., 2006), thermal gradient (Strasser et al., 2002), human activities (Shenck & Paradiso, 2001), etc.

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The available energy in the microsystems surrounding environment has to be extracted and converted into usable energy, and transported to the application. Consequently, embedded autonomous microsystems, and more precisely energy harvesting processes, induce the consideration of specific elements, namely

– a source which the energy is extracted from,
– a converter to transform this energy
– transportation elements.

For the design of embedded microsystems functioning by harvesting energy from their environment, efficiency is a crucial feature because the available energy is comparable to the one required for the application. Consequently, energy losses must be minimized. If the design of efficient devices is already a target issue, the new idea stems from the abundance and multiplicity of available energy sources, when considering embedded autonomous microsystems. Indeed, for most embedded applications, designers have to choose from various energy sources. Until now this choice has been mainly based on the professional experience of designers. There is no systematic approach to help them in the initial phases of the design process.

Our aim is to develop a decision support system dedicated to the early phases of the design process, and more precisely between the concept research and the embodiment design phases. This method is based on dividing products into Source, System and Sink, and defining criteria suitable for the classification of different alternatives. To evaluate these criteria, we introduce measurement principles. Our approach is systematic and based on high level invariants as well as the notion of antagonism, by considering functional and induced effects. All these notions are detailed hereafter.

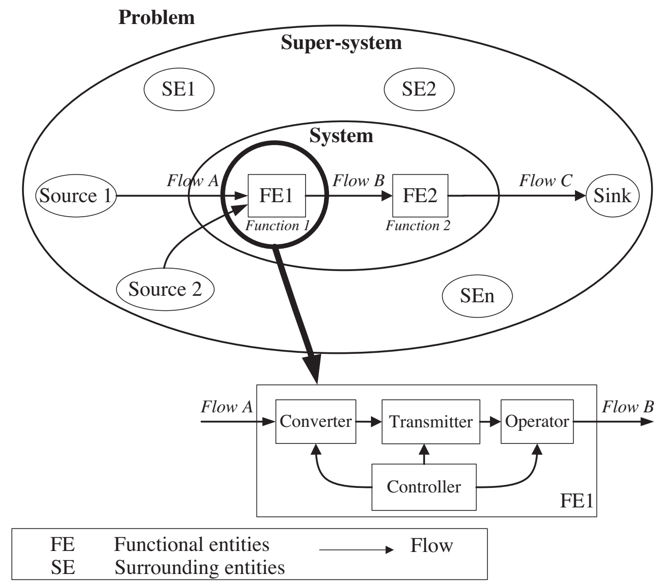

Fig. 1. Global representation of the design problem.

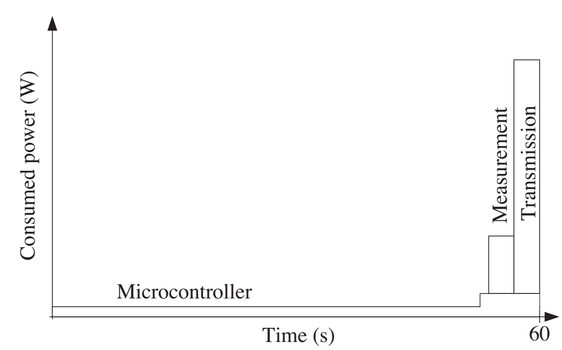

Fig. 2. Periodic activity of the microsystem.

2.2. Structuring energy systems

2.2.1. Organic representation

Microsystems are tiny devices equipped with measurement and communication parts, embedded intelligence and energetic autonomy. Thus, their behavior is highly dependent on their environment. This is particularly true when dealing with microsystems powered by energy harvesting circuits.

As a result, our approach is observed from a functional point of view. We consider the System (the energy harvester) and the Super-system (ie. the surrounding environment). They can be broken down into functional entities (FE) and surrounding entities (SE) respectively. Each functional entity is associated with actions and flows, whereas surrounding entities are only related to flows (Fig. 1).

2.2.2. Definition and classification of flows and effects

Pahl and Beitz decomposed the notion of flow into Material, Energy and Signal (MES) Pahl & Beitz, 1984. A classification of these flows is then introduced (Hirtz et al., 2002). It helps us to split them into elementary flows and associate them with actions that are listed in functional bases (Scaravetti et al., 2003). Flows represent the inputs and outputs of the System's distinct entities (Fig. 3).

Entities realize functions by transforming an input flow into an output one. This leads to the generation of effects that can be functional or induced. Functional effects are useful (U) and contribute to the realization of the main function, whereas induced effects can be either neutral (INE) or harmful (also called antagonist) (IAN). They can damage or lead to dysfunctions of the considered entity (wearing, noise, overheating, deformation, etc). All of these effects are related to physical phenomena from which we can deduce conservative laws, inertial conditions and boundary conditions that will be used in the detailed design phase (Altschuller, 1984; Scaravetti et al., 2005) (Fig. 1).

2.2.3. Functional decomposition

Functional decomposition enables us to identify the different entities which make up the System and Super-system, and the flows circulating between these entities. This identification is required in the design of embedded autonomous microsystems powered by energies available in the surrounding environment.

We break the system down into entities and we use hierarchical structuring proposed by. Savransky (2000). The laws of completeness of system parts, defined in TRIZ and Nadeau (Nadeau et al., 2005) distinguish four main elements that are necessary to carry out a functional action:

– Converter: it transforms the input flow into other types of flows. Dual variables associated to MES flows are thus modified.
– Transmitter: it enables flow transmission without changing the nature of the energy.
– Operator: it can be a converter or a transmitter
– Control element: it ensures the transmission of the functional flow (dual variables remain unchanged).