Chapter 2
Smart Electronic Systems: An Overview

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2.1 Introduction

The term *smart systems* is quite general and identifies a broad class of intelligent and miniaturized devices that are usually energy-autonomous and ubiquitously connected. They incorporate functionalities like sensing, actuation, and control. In order to support these functions, they must include sophisticated and heterogeneous components and subsystems, such as digital signal processing devices, analog devices for RF and wireless communication, discrete elements, application-specific sensors and actuators, energy sources, and energy storage devices (as shown in Fig. 2.1).

These systems take advantage of the progress achieved in miniaturization of electronic systems, and are highly energy-efficient and increasingly often energy-autonomous, and can communicate with their environment.

Thanks to their heterogeneous nature, smart embedded and cyber-physical applications are able to deliver a wide range of services, and their application may lead to provide solutions to address the grand social, economic, and environmental challenges such as environmental and pollution control, energy efficiency at various scales, aging populations and demographic change, risk of industrial decline, security from micro- to macro-level, safety in transportation, increased needs for the mobility of people and goods, health and lifestyle improvements, just to name the most relevant [19].

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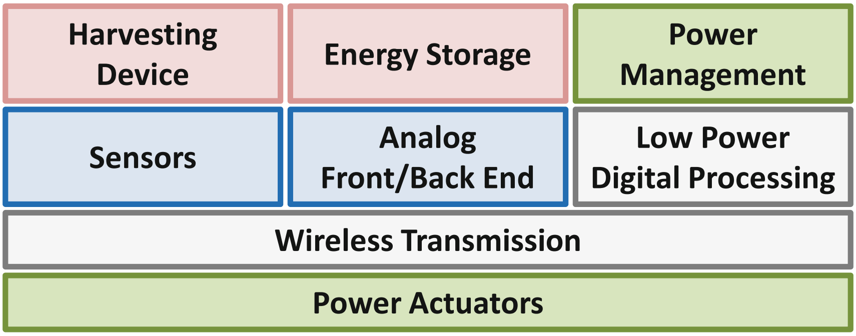

Fig. 2.1 Typical components and domains of a smart electronic system

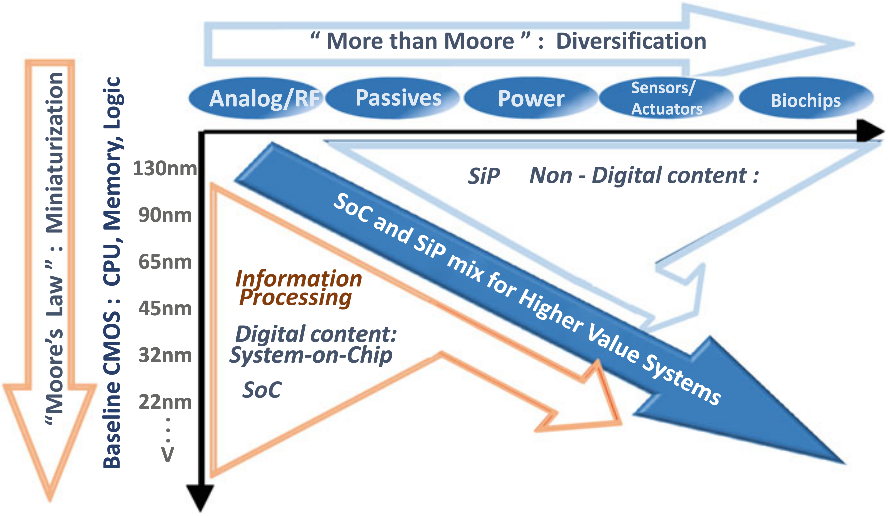

Fig. 2.2 Smart systems as the convergence of more Moore and more than Moore

The deployment of smart systems requires the concurrence of technological advancements both in the dimension of (1) increased diversification and heterogeneity in a single device, i.e., technologies such as 3D integration, Systems-in-Package, and (2) increased integration capabilities of silicon technologies. These two dimensions are the well-known technology paths described in the International Technology Roadmap for Semiconductors (ITRS) and that are traditionally considered as complementary directions. In that respect, smart systems as a category of devices represent the convergence between these two dimensions, as depicted in Fig. 2.2 [25].

Recent years have witnessed a significant increase of the relative weight of the "More-than-Moore" component in the industry evolution; this will allow to establish a new "virtuous cycle" no longer based solely on device scaling but relying on other innovations at the system, technology, circuit, and device levels, which will need to address not just front-end technologies but also backend/packaging ones. Such opportunities are counterbalanced by challenges related to the integration and manufacturing of such devices, the development of tools and flows for the automated design of these systems, as well as the coordination of design teams that reflect the heterogeneity of smart system in their competences (mechanics, electronics, communication, optics, computer science, etc.).

2.1.1 Evolution of Smart Systems

The smart systems community traditionally classifies smart systems by their degree of autonomy, meant as both in terms of reduced need of external supervision and control and of energy self-sufficiency. This has brought to the traditional three-level categorization into "generations" of smart systems [19], corresponding to different extents to which the key functionalities are implemented.

First Generation Smart Systems integrate sensing and or actuation as well as signal processing to enable various types of actions. Such systems have already been successfully deployed in many application domains, e.g., personal devices to monitor the health status of persons or safety systems in automotive applications.

Second Generation Smart Systems add perception features and are predictive and adaptive systems, possibly with self-test capabilities. Moreover, they include network connectivity of some type and advanced energy scavenging and management capabilities. An example of this category are smart RFID labels that are able to measure multiple parameters (temperature, acceleration, etc.) for transport real-time monitoring.

Third Generation Smart Systems add human-like perception on top of second generation systems. They interact independently and without external control or decision, and implement systematically features like self-calibration, self-test, and self-healing. An autonomously driving car is the most typical example of such a system.

Systems of different generation evolve at different speeds; while for first-generation systems their optimization is still an R&D challenge, in second- and third-generation systems still basic scientific, materials and manufacturing challenges have to be assessed. The co-existence of different generations of systems suggests that adopting a comprehensive design approach will be likely to yield competitive products today and keep them competitive in the future versions.

This chapter presents an overview of three relevant aspects of smart systems: the application domains (Sect. 2.2), their architectures (Sect. 2.3), and the main design challenges (Sect. 2.4), from a system-level perspective and with the objective of providing a sort of guided path through the topics dealt in the remainder of the book.

2.2 Application Domains

The current technology and market trends show that smart systems are used in an increasingly wide range of contexts and environments, from everyday life tasks to highly complex and critical missions. The architecture and the implementation of each system needs to comply with the application requirements and constraints in terms of functionality, performance, dependability, autonomy, and safety, while keeping design and manufacturing costs as low as possible.

In the following, a list of application domain categories is reported. The purpose of this list is the identification of the smart system application domains of today and the immediate future, with the aim of being as much general and exhaustive as possible. Actual examples of smart systems are provided for each category: some of them are concepts only, others are prototype boards or products, and others have already reached the status of miniaturized devices.

2.2.1 Transportation

Transportation scenarios include land (i.e., road, off-road, rail, cable, and pipeline), sea, and air (i.e., air and space) for humans and goods in general. Smart systems can be used within a moving vehicle or can take part of infrastructures and networks for transportation enhancement and regulation. Some smart device examples in this category include heterogeneous sensor-based GPS enhancement systems, engine sensing and control systems, electronic stability control systems for vehicles, parking sensors [24], car theft detection and monitoring devices, airplane balancing aids, vibration analysis instrumentation for model optimization and unmanned aerial vehicle (UAV) attitude, and operating controls.

Figure 2.3a shows a smart system example in this application domain, i.e., an accelerometer-enhanced tire pressure monitoring system (TPMS) [8, 20]). Such system measures important dynamic variables, e.g., forces, load transfer, actual tire road friction (kinetic friction), and maximum tire road friction available (potential friction), in order to actively guarantee the car safety. The data acquisition system is based on a distributed architecture composed of a number of complex intelligent sensors inside the tire that form a wireless sensor network with coordination nodes placed on the body of the car. The single sensor node represented in Fig. 2.3b is composed of MEMS sensors, analog and digital circuits (including a microcontroller), and a UWB radio link. In addition, the sensor node energy is supplied by means of harvesting, which may be based on electromechanical vibrational energy or on electromagnetic coupling with an external illuminator.

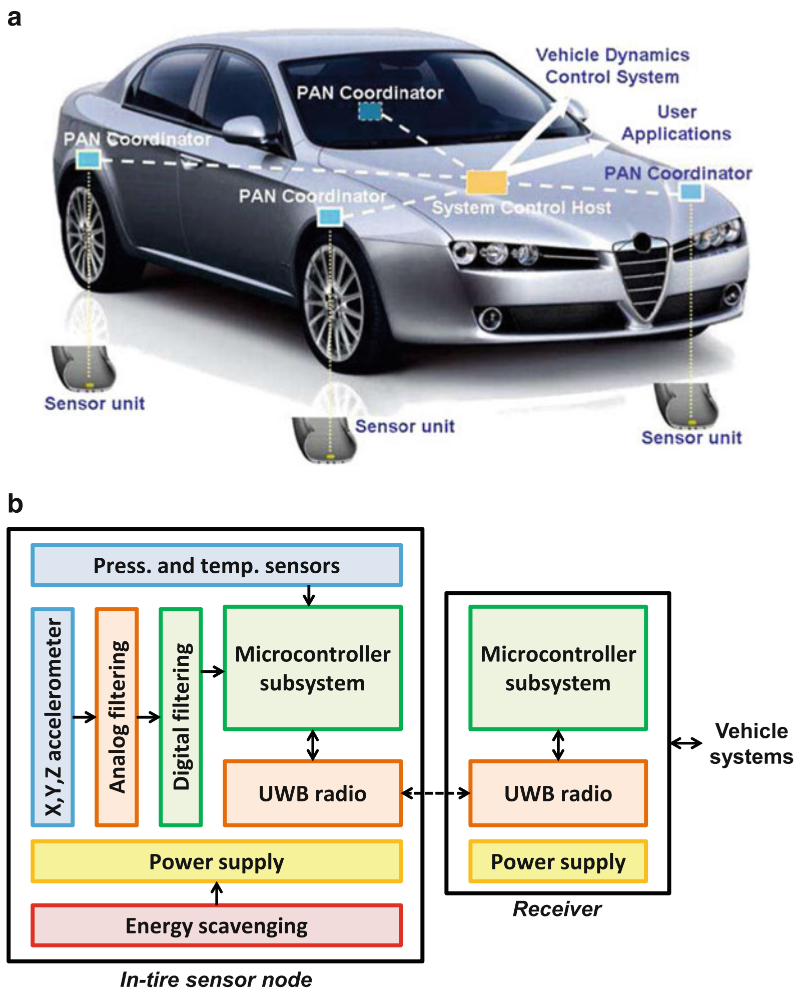

Fig. 2.3 Intelligent tire system presented in [8]: (**a**) overview of the system architecture and (**b**) architecture of the sensor node-receiver system

The design of this system and especially of the in-tire sensor node is extremely challenging due to the very limited available energy combined with strict application requirements for data rate, delay, size, weight, and reliability in a highly dynamic environment. The integration of the sensor node is especially critical due to the harsh environment, low-power constraints, and limited size: a compact circuit board hosts all the sensor node components.

2.2.2 Telecommunications

This application domain deals with the generic transmission of information (e.g., audio, video, text, data from sensors, alarm events) through different media, such as cable, air, water, or void. Smart systems are typically used to improve performance and reliability of existing infrastructures, or to explore new areas and potentials.

In this category, possible examples are given by MEMS fiber-optics switches, energy harvesting and autonomous radio repeaters [5], optical MEMS-based devices for lightwave communication [9], and RF MEMS-based tunable filters and antennas [23].

2.2.3 Military and Defense

This application field includes devices used in defending countries from threats both foreign and domestic and specifically includes systems for command, control, communications, computing, intelligence, surveillance, reconnaissance, and targeting (C4ISRT).

Examples include systems for friendly forces monitoring, equipment and ammunition, systems for the reconnaissance of opposing forces and terrain, microrobot surveillance [3], sensor-enhanced targeting systems, battle damage assessment, and nuclear, biological, and chemical attack detection and reconnaissance.

2.2.4 Safety and Security

This application domain includes smart systems aimed at delaying, preventing, and otherwise protecting against accidents or crimes, which may cause adverse effects to people or organizations.

Examples include free fall sensors and human airbags [17], chemicals/radiation sensing systems, and anti-theft and anti-intrusion sensor systems.

Figure 2.4a shows an example of mobile human airbag, i.e., a protective system based on the idea of automobile airbags systems [17]. This system has two modules: a sensing module (μIMU) and an inflator that connects to two nylon airbags. When the μIMU detects a fall, it triggers an inflator, which then deploys the airbags before impact to protect the human body. The gas is supplied from a handy compressed gas cylinder, rather than the combustion of chemicals. The main components of the independent mobile airbag system are a set of MEMS sensors (accelerometers and gyroscopes), an embedded microcontroller unit performing DSP functions, and a mechanical airbag deployment system. The system is powered by means of lithium batteries. The sensors are directly connected to the A/D converters inside the microcontroller. The mechanical part includes the inflator structure for compression,

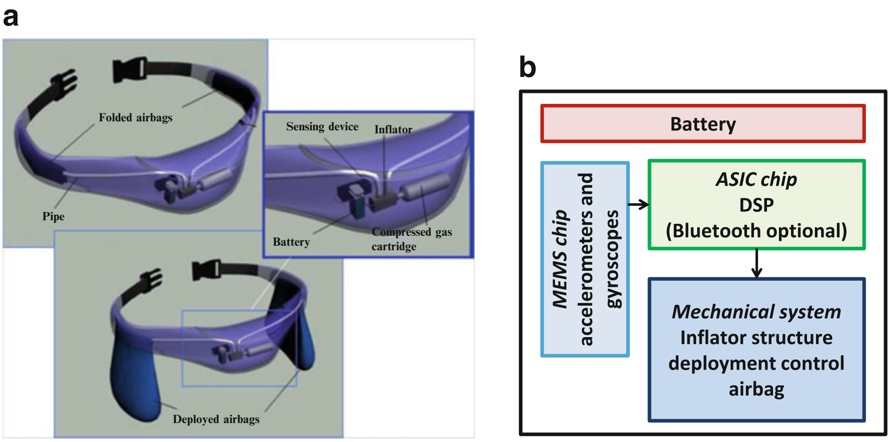

Fig. 2.4 Intelligent mobile human airbag system of Shi et al. [17]: (**a**) system components and (**b**) system architecture

airbag deployment control, and airbag design. Figure 2.4b provides a high-level architectural view of the system.

Design and simulation of this type of system require merging non-miniaturized mechanical parts and electronic components (sensors and digital hardware including the microcontroller and the software), also taking into account the real-time application requirements.

2.2.5 Home Automation

Smart systems aimed at improving convenience, comfort, energy efficiency, and security to residential buildings fall into this category, also known as domotics.

Examples are energy-efficient distributed heating, ventilation and air conditioning (HVAC) sensing and control systems like the energy management system presented in [14], acoustic monitoring systems, audio/visual switching and distribution systems, and light control systems.

2.2.6 Industrial Automation and Logistics

Industrial automation deals with the optimization of energy-efficient manufacturing systems by precise measurement and control technologies. Logistics concentrates on the flow of goods between the point of origin and the point of destination to meet the requirements of customers and corporations, and it involves the integration

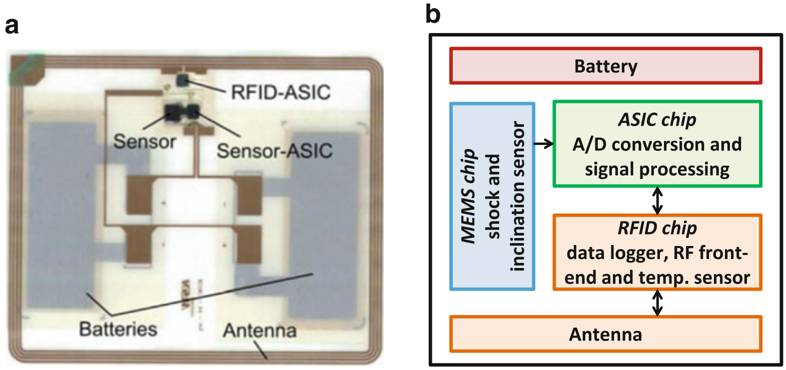

Fig. 2.5 Smart active RFID label presented in [8]: (**a**) system components and (**b**) system architecture

(and interaction) of information, transportation, inventory, warehousing, material handling, and packaging, and often security.

This category of smart systems includes examples such as sensor-enhanced robot controls, manufacturing plant monitoring systems, and active RFID tags as the one showed in Fig. 2.5a [16].

Such active radio frequency identification label is designed for the monitoring of shock, inclination, and temperature during transportation processes. The system architecture is shown in Fig. 2.5b. Besides the components of a passive label "RF front-end, memory, and antenna" the system contains a MEMS inertial sensor system, a temperature sensor, a data logger, and a printed battery. The battery works as autonomous energy source for the inertial sensor system, the temperature sensor, and the data logger. The energy for the radio communication of the label is generated by the antenna from the electric field emitted by the reader.

All these elements have to be integrated on the thin label substrate fulfilling specific requirements for the sensor system like low power consumption, high signal to noise ratio, high temperature stability, and low device/sensor thickness.

2.2.7 Laboratory Equipment

Today's integrated advanced technologies allow the fabrication of compact, accurate, and energy-efficient instrumentation to be used for analysis, measurement, and manipulation in a wide range of fields.

In this category, possible examples are spectrometers and interferometers [16], MEMS scanners and projectors [9], and intelligent motion surfaces for manipulation such as [26].

2.2.8 Environment and Food/Beverage

Multi-sensing microsystems can be used for environmental applications (including monitoring and treatment) or food and beverage quality and safety.

Examples in this category include sensor nodes (within networks) for environment monitoring (e.g., to study influences on crops, livestock) based on system-on-chip design [2]. Other examples are also general-purpose microsensor modules [7], macroinstruments for large-scale earth monitoring and planetary exploration, forest fire detection and flood detection sensors, animal movement tracking systems, and tagging/tracking in supply chains (RFID).

2.2.9 Healthcare and Biomedical

This category includes systems aimed at generally improving health, by means of delivering diagnosis, treatment, care, and support of patients in healthcare systems. Typically different disciplines are involved in this field, including biology, genetics, physiology, physics, and bioengineering. Given the increasing importance of these application domains, various examples are available, such as biochips, microinstrumentation for microinjection and cell-manipulation, microsystems interacting with the human body, lab on chips including sensors and active microfluidics, systems for tele-monitoring of human physiological data, tracking and monitoring systems for doctors and patients inside a hospital, drug administration systems, and smart textiles for health monitoring.

Among the available case studies, it is worth mentioning the self-powered wireless pulse oximeter presented in [21], a wearable battery-free wireless electroencephalograph (EEG) [22], breath monitoring systems, limb tracking systems, wireless multi-sensor microsystems for human physiological data monitoring [4], and wearable posture corrective systems using biofeedback [10].

2.2.10 Power Generation, Distribution, and Harvesting

In this application scenario smart systems convert energy from different sources, store and distribute electricity to the users. Energy harvesting usually refers to the process by which energy is derived from external sources, captured and stored for small, autonomous devices at a low scale.

Sensor-based systems for control of wind turbines and portable, multipurpose energy harvesting bracelets [18] are just some examples of this increasingly studied field in the today's efforts aimed at lowering the carbon footprint.

2.2.11 Consumer Applications

Consumer electronics refer to equipment intended for everyday use, most often in entertainment, communications, and office productivity. This market segment includes cellular communication, personal computing, digital photography, multimedia and entertainment, fitness appliances and gaming, and it is characterized by fast cycle time, low product price and wide diffusion.

Smart system examples in this category include wireless sensor devices for statistical data logging (e.g., on balls, players, field, etc.), general-purpose microsensor modules [7], impact-sensing accelerometer systems for sport helmets [13], sailing sports wind analysis systems, vibration reduction systems in sporting goods (tennis rackets, golf clubs, etc.), smart lighting modules, augmented reality devices [12], interactive screens and interactive museums.

New smart lighting modules are becoming popular in lighting appliances for building environments.The smart lighting modules are multi featured devices that extend their functions beyond the lighting, by adding security, safety, comfort, and wireless control functions to the lighting devices. To provide this broad range of functionalities, smart lighting modules integrate components from different technological domains, hence, they can be included in the class of smart electronic systems. A real example is the smart bulb showed in Fig. 2.6.

The smart bulb is a fully controllable light bulb, embedding light changing features, complex RF communication, sensors and actuators. The bulb's light source, heat sink, and lens system are integrated with the sensors and actuators. An electronic controllable light shape system is also typically integrated in the bulb. The smart bulb has wireless secure communication channels and is remotely

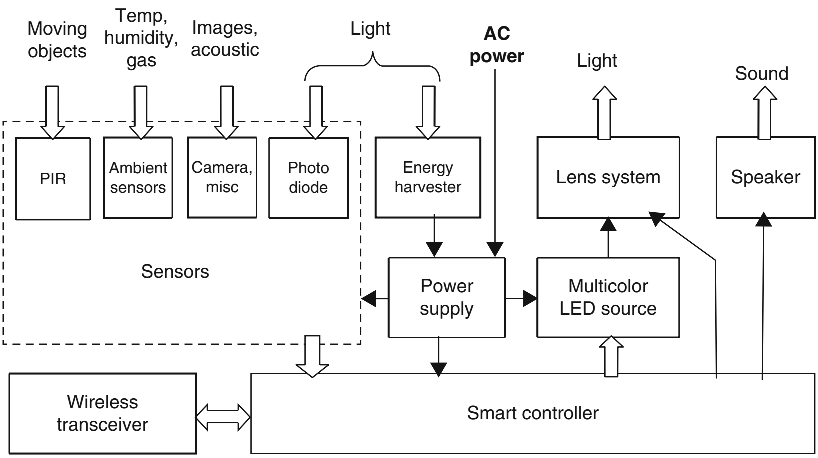

Fig. 2.6 The smart bulb architecture

controllable, also acting as a network device capable of routing data packets and related information to other network devices. The multi featured bulb opens new functions in the lighting sector expanding it beyond the state of the art, which is up to now represented by the Philips lighting "HUE" bulb [15].

2.3 Smart System Architectures

2.3.1 Module-Level

As mentioned above, smart embedded systems incorporate heterogeneous components, i.e., from different technology domains and providing various functions. For all systems the basic building blocks are conceptually similar, however, in each instance the specific implementation can greatly differ. A general classification of the basic building blocks is the following (see Fig. 2.7):

- *Energy Source*: Harvesting devices capable of converting energy of a physical source into electricity, such as solar (e.g., photovoltaic cells), thermal (e.g., thermoelectric energy generators), and mechanical (e.g., piezoelectric scavenger) energy generators.
- *Energy Storage*: Devices capable of storing a limited amount of electrical energy in the potential, kinetic, chemical, or other forms of energy, and restoring the stored energy back to the electrical energy on demand. The main types of energy storage devices which are generally used for smart embedded systems are batteries, supercapacitors (or ultracapacitors), and fuel cells.
- *Energy Conversion*: Components that in general convert electric energy from one form to another. Their functionality is fundamental in order to transfer the energy within the system and hence to realize the power supply to all components of the system. Energy conversion devices can be typically divided into DC–DC, AC–DC, DC–AC, and AC–AC converters.
- *Power Devices*: Energy management components such as power diodes, thyristors, power FETs, and power MOSFETs.

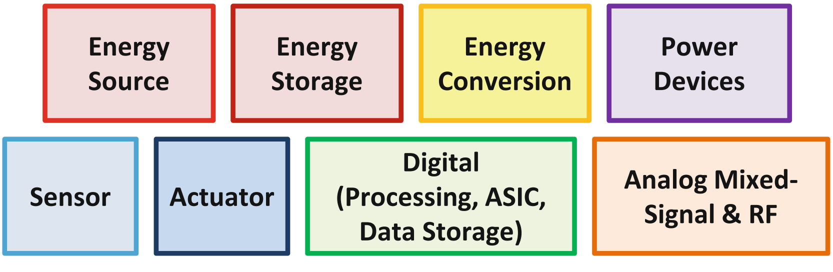

Fig. 2.7 Basic components included in a smart system

- *Sensor*: Devices capable of detecting events or changes of a physical quantity and converting them into an electrical signal. Examples are MEMS, electro-optical sensors, image sensors, thermocouples, and acoustic sensors.
- *Actuator*: Devices capable of converting an electrical signal into another form of energy, such as electric motors, light-emitting diodes, and loudspeakers.
- *Digital*: Digital hardware blocks for processing and storing digital information, such as processor or digital signal processing (DSP) cores, digital accelerators, device controllers, and also application-specific ASICs. This category includes also the embedded software executed by the hardware blocks.
- *Analog Mixed-Signal and RF*: Analog components such as RF communication devices, signal conditioning, and interface circuits.

2.3.2 System-Level

Given the general classification of basic components defined above, smart systems can also be categorized based on their general module architecture and main features. Each miniaturized intelligent system falls in one of the following categories, defined by a set of characterizing functions.

- *Sensor Node (Within a Network)*: Characterizing functions are sensing, data processing, data storage, communication. A sensor node is a device that acquires data from the environment, optionally performs some kind of elaboration, and either stores data or directly transmits it to other devices (usually through a wireless channel). Low power consumption and maintainability are very common requirements, especially for remote devices.
- *Actuator Node*: Characterizing functions are data processing, actuating, communication. This type of device runs operations (e.g., turning on or off some other device) when programmed or when it receives the required command from the network. Reliability is fundamental when safety- or mission-critical tasks are executed.
- *Communication Node*: Characterizing functions are data processing, data storage, communication. This device communicates within a network and optionally elaborates data. It can operate as a remote database, a repeater, or an intelligent node connected to sensors and actuators and can run at a high hierarchical level.
- *Autonomous Sensor and Actuator*: Characterizing functions are sensing, data processing, data storage, actuating, communication. These devices include mainly all the features of the previous categories, incorporating communication interfaces, sensors and actuators, which can be used for other devices control or for self-displacement.

From a higher level of abstraction, smart electronic systems can not only consist of a single heterogeneous device, but can also be arranged in various architectures with different degrees of complexity. The following categories summarize the main system-level architectures characterizing the example devices showed in the previous section.

- *Single Module*: A single-module smart system can perform all operations related to its purpose without communicating to a host or other devices.
- *Host-Client System*: A host-client system is based on two smart (sub-) system modules, where one typically is used to access the information stored or elaborated by the other, or to program or control it.
- *Network*: The system comprises many devices, either communicating among them or connected through a network that may also be built on a hierarchical model. The devices can share a common module architecture or can be heterogeneous (e.g., many sensor nodes and an intelligent data collector node). Sensor networks, which represent one of the most common application of smart systems, are surveyed in [1] and [11].

2.4 Design Challenges

Smart embedded systems are produced with very different technologies and materials. This is even more evident from the heterogeneous categories of components listed in Sect. 2.3.1. Therefore, besides the design of the individual components and subsystems, the main challenge for smart system designers lies in the integration of a number of functionalities, materials, and technologies. In general, there are essentially two dimensions of integration that represent the main obstacle towards mainstream design of smart systems: *technological* and *methodological*.

As already experienced in other domains (e.g., digital and analog design), technological issues have been the first concern for research and industrial actors. Today manufacturers are able to package all aforementioned components more densely, combining the various domains in a single package. This is possible thanks to advanced packaging technologies such as System-in-Package (SiP) and chip stacking (3D IC) with through-silicon vias (TSVs). SiP technology is a good solution because it allows combining components and subsystems with different processes, and mixed technologies using the state-of-the-art advanced IC packaging technologies with minor impact on the IC chip design flow.

Nevertheless, the assembly of intrinsically heterogeneous components and the continuous miniaturization and integration push, motivated by the increasing market demand for faster, cheaper, and more performing devices, raise the need for new design and simulation methodologies. Such methodologies are fundamental for exploring the design space in order to find the most efficient trade-off between performance and involved resources, and for evaluating and validating system behavior taking into account the interactions between closely coupled components of different nature.

Considering the development of a complex system it is possible to identify several main steps characterized by their own specific peculiarities: the architecture definition, the design implementation and its validation, and the product engineering and industrialization.

During the design phase the application specifications are analyzed, the appropriate system architecture is defined usually following a top–down approach and the appropriate building blocks are identified when already available, or otherwise requested to be developed. The development team is asked to propose a solution able to cover the application functionalities supported by a detailed feasibility study. To achieve this task in a sustainable way, similar systems are evaluated when possible, expected system performances are addressed, subsystems and building components are detailed and final system cost forecasted. The mentioned feasibility analysis is of primary importance because it is the pillar on which company management takes the decision to proceed or not in the development. Considering the rhythm on which new high-tech complex products are presented on the market, to grant an appropriate level of competitiveness another key factor is the ability to have fast and effective evaluation about the new addressed solution especially on its innovative features. It is now clear the need of a platform able to manage the smart system complexity and provide quick but pertinent feedbacks about functionalities, fair heterogeneous component interoperability, reasonable forecast on sensible parameter working ranges (i.e., speed, power consumption, autonomy, efficiency, etc.), adherence on imposed regulations or applicable standards, and at least a rough estimation of underlying costs. It cannot be neglected the fact that in the feasibility phase several different proposals, architectures, and technologies are often addressed, many metrics and complex figures of merit are adopted to identify, from the beginning, the most promising approach. Also for this purpose, the capability to rapidly evaluate different scenarios, replacing building blocks, trying different basic components represent an obvious advantage in order to achieve a better awareness for all the further development steps.

System integrators typically have separate tools to model the environment. Design requires merging heterogeneous units from cross-sectional, separate, and so far loosely correlated domains. Subsystems are designed based on diverse assumptions and techniques, and are typically modeled with digital, multi-physics, or analog models, which are available at specialized design houses and silicon makers in various forms. The involved components are usually described using different languages, relying on different models of computation and modeling parameters, and need to be jointly simulated at various abstraction levels.

Figure 2.8 shows an example of operating scenario for a typical smart embedded system. The functional interactions within the components and between the components and the environment must be considered when designing the system: among them there are analog signals, digital interfaces, mechanical interactions (e.g., a sensor transfer function). In addition to this it is increasingly important to consider non-functional interactions that may have an impact on the behavior of the complete system, either on its specific functionalities or on power consumption, life duration, etc.: they may correspond to mechanical interference, heat flow, RF interference, etc. In Fig. 2.8, only thermal flows have been reported as non-functional interactions,

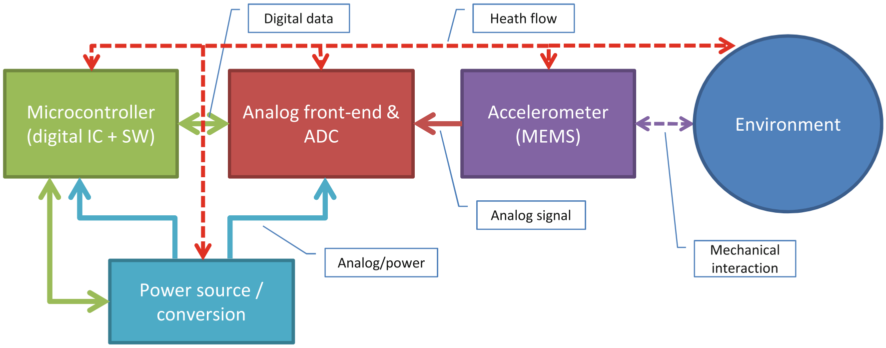

Fig. 2.8 Example of smart embedded system scenario with interactions among components and with the environment

which may lead to effects such as the increasing signal propagation delay within the microcontroller due to ambient temperature, the rise of temperature of the power conversion elements, and the variation of the accelerometer transfer functions due to heating.

The basic building block of a digital circuit has been a single transistor or standard cell for years, during the rising of the digital era; today a microprocessor core can be instantiated and networked by a designer with the same simplicity with which a flip-flop could be inserted in a design 20 years ago. The main difference is that now this seemingly immediate operation entails even deeper and different physical interactions in the system, and therefore, wider interdisciplinary design basics on one hand, and advanced software tools capabilities on the other [6].

The designer needs to be aware of the description of each interaction, including the nature of the communication, its time scale, and its detail level. The design tool should enable the instantiation and connection of the models of different components, and then the simulation of the entire system. The model of each component should be sufficiently accurate so as to show application-relevant effects but abstract enough so as not to excessively slow down the simulation. Different selectable component models may be useful, with variable levels of detail depending on the application requirements, and with defined validity ranges (e.g., temperature and frequency). The component models to be used, composing a "library" for the system integrator, may have different sources, depending on their specific development flow, but they need to be specified in a shared format readable by the design platform, they may be the output of abstraction flows of lower-level models produced by the device designers; otherwise, the models may be built by the devices suppliers or directly by the system integrators based on datasheets and characterization tests. It should as well be possible to model non-miniaturized, electric or mechanical devices. Roughly speaking, the device model to instantiate should appear as a parameterizable "black box" to conceal design details that cannot be appreciated by the system integrator and to limit the design complexity. In addition to this, it is needed to describe the system assembly, including the board (substrate) material, the distance between components and any contact surfaces between them. These points have a substantial effect on the system behavior, especially when, coherently with the miniaturization trend, SiPs are concerned. This may also require changing some parameters in the device model so as to adapt its behavior to the desired configuration. Hierarchical modeling and partitioning are key features when describing complex systems. The user should be able to describe the relevant features of the use environment together with its interaction with the system, including temperature, RF fields, vibrations, etc., in static and dynamic conditions.

Finally, design constraints need to be described and propagated to subsystems and components in a top–down stream. The design tool should provide different system-level simulation options by trading-off accuracy (varying model accuracy, activation/deactivation of physical models, time scale, etc.) and speed. In this way, initial design space exploration could be easily and quickly performed (maybe using only a single transaction-level simulator engine), while in later stages pre-prototype design validation would be achievable together with a constraints check; if needed co-simulation with logic, circuital, finite element method (FEM) engines, etc., should also be exploitable in a seamless way.

References

1. I. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, Wireless sensor networks: a survey. Elsevier Comput. Netw. **38**(4), 393–422 (2002)
2. D. Barnhart, T. Vladimirova, M. Sweeting, System-on-a-chip design of self-powered wireless sensor nodes for hostile environments, in *Proceedings of IEEE Aerospace Conference*, March 2007, pp. 1–12
3. S. Bergbreiter, K. Pister, Design of an autonomous jumping microrobot, in *Proceedings of IEEE International Conference on Robotics and Automation*, April 2007, pp. 447–453
4. Y. Chuo, M. Marzencki, B. Hung, C. Jaggernauth, K. Tavakolian, P. Lin, B. Kaminska, Mechanically flexible wireless multisensor platform for human physical activity and vitals monitoring. IEEE Trans. Biomed. Circuits Syst. **4**(5), 281–294 (2010)
5. Cooper US, Inc. Energy harvesting (EH) power supply and repeater. (2015). Available: http://www.cooperindustries.com/content/public/en/power_systems/products/automation_and_control/amr_ami.html
6. M. Crepaldi, et al., Towards multi-domain and multi-physical electronic design. IEEE Circuits Syst. Mag. **15**(3), 18–43 (2015)
7. D. Culler, J. Hill, M. Horton, K. Pister, R. Szewczyk, A. Woo, MICA: the commercialization of the microsensor motes. Sensors **19**(4), 40–48 (2012)
8. S. Ergen, A. Sangiovanni-Vincentelli, X. Sun, R. Tebano, S. Alalusi, G. Audisio, M. Sabatini, The tire as an intelligent sensor. IEEE Trans. Comput. Aided Des. Integr. Circuits Syst. **28**(7), 941–955 (2009)
9. Fraunhofer IPMS. MEMS scanners. (2015). Available: http://www.ipms.fraunhofer.de/en/applications/mems-scanners.html
10. A. Gopalai, S. Senanayake, A wearable real-time intelligent posture corrective system using vibrotactile feedback. IEEE/ASME Trans. Mechatron. **16**(5), 827–834 (2011)
11. S. Gowrishankar, T. Basavaraju, D. Manjaiah, S. Sarkar, in *Proceedings World Congress on Engineering*, vol. 1, 2008, pp. 176–187

12. R. Herold, U. Vogel, B. Richter, OLED-on-CMOS based single chip microdisplay and image sensor device, in *Proceedings of International Display Workshop*, 2010, pp. 339–340
13. D. Nosowitz, NFL testing helmets with impact-sensing accelerometers for concussion analysis (2011). Available: http://www.popsci.com/technology/article/2011-01/nfl-test-helmets-impact-sensing-accelerometers-concussion-analysis
14. N.-H. Nguyen, Q.-T. Tran, J.-M. Leger, T.-P. Vuong, A real-time control using wireless sensor network for intelligent energy management system in buildings, in *Proceedings of IEEE Workshop on Environmental Energy and Structural Monitoring Systems (EESMS)*, September 2010, pp. 87–92
15. N.V. Philips , Philips hue. (2015). Available: http://www.meethue.com/
16. D. Reuter, T. Gessner, Smart systems integration by using micro- and nanotechnologies, in *Proceedings of International Multi-Conference on Systems, Signals and Devices*, 2009, pp. 1–8
17. G. Shi, C.-S. Chan, G. Zhang, W. Li, P. Leong, K.-S. Leung, Towards a mobile airbag system using MEMS sensors and embedded intelligence, in *Proceedings of IEEE International Conference on Robotics and Biomimetics*, December 2007, pp. 634–639
18. T. Singh, Hybrid power bracelet runs on solar energy and body heat, inhabitat – sustainable design innovation, eco architecture, green building (2010). Available: http://inhabitat.com/hybrid-power-bracelet-runs-on-solar-and-thermal-energy/
19. Smart Systems in the Multi-Annual Strategic Research and Innovation Agenda of the JTI ECSEL, Part D, EPoSS Industry Association, March 2014
20. N.H. Tan, Tire pressure monitoring system (TPMS) with SP37, in *International All-Terrain Vehicle Symposium*, 2010
21. T. Torfs, V. Leonov, R. Vullers, Pulse oximeter fully powered by human body heat. Sens. Transducers J. **80**(6), 1230–1238 (2007)
22. M. Van Bavel, V. Leonov, R. Yazicioglu, T. Torfs, V. Van Hoof, N. Posthuma, R. Vullers, Wearable battery-free wireless 2-channel EEG systems powered by energy scavengers. Sens. Transducers J. **94**(7), 103–115 (2008)
23. Wispry, Inc. Technology – About MEMS. (2013). Available: http://www.wispry.com/technology.php
24. J. Wolff, T. Heuer, H. Gao, M. Weinmann, S. Voit, U. Hartmann, Parking monitor system based on magnetic field sensor, in *Proceedings of IEEE Intelligent Transportation Systems Conference*, 2006, pp. 1275–1279
25. G.Q. Zhang, A.J van Roosmalen, The changing landscape of micro/nanoelectronics, in *More than Moore: Creating High Value Micro/Nanoelectronics Systems* (Springer, Berlin, 2009)
26. L. Zhou, Y.-A. Chapius, Y. Fukuta, Y. Mita, F. Braun, H. Fujita, Architecture and implementation of distributed control system for MEMS-based intelligent motion surface, in *Proceedings of IEEE International Symposium on Industrial Electronics*, June 2005, vol. 3, pp. 1043–1048

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