Building Smart Adaptable Cyber-Physical Systems: Definitions, Classification and Elements

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Abstract. The provision of systems that join the information technologies with the physical world has been one of the most popular issues in research in the last fifteen years. Nevertheless, the complexity associated with these systems prevented many authors from providing a theoretical formalization. Even it is difficult to find a consensus name or a definition for this new type of systems. Therefore, in this work we propose a theoretical and technical formalization for these solutions, which includes a name at the forefront of research: smart adaptable cyber-physical systems (SACPS). We also present a complete definition for the SACPS, and explain the elements and subsystem interaction.

Keywords: Smart Adaptable Cyber-Physical Systems · SACPS · RFID · Wearable technologies · Wireless HAN · Cybernetic devices

1 Introduction

Making a research in the smart environment field is complicated. The causes are, overall, the term's ambiguity and the lack of a bibliographic base (extended and coherent) which fixes the limits, elements, technologies, etc. in this kind of systems.

Therefore, the main objective of this work is presenting a new concept, with technical character and without ambiguity, which delimits the application area of the (until now) so-called "smart environment". We are talking about Smart Adaptable Cyber-Physical Systems (SACPS).

The rest of the paper is organized as follows: In section two we review the previous efforts of some authors for defining this type of systems and try to extend them with the now-a-days knowledge. Section three presents a classification for SACPS. Finally, section four is dedicated to the elements which make up a SACPS and to their functions.

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2 History, Definition and Related Work

The first efforts for integrating information technologies in the physical world were based on electronics. Thus, from 2000, several terms have appeared in the literature and, overall, have been proposed in conferences, to refer to smart distributed electronic systems (more or less embedded in the physical world): Smart Home [1, 2], Smart Office [3], Intelligent Home [4], Smart Environments [5], Adaptive Versatile Environments [6], Interactive Spaces [7], Problem-Solving Environments [8], etc.

In a parallel way, for these terms some definitions appeared. Thereby, in 2000, [9] said that "A smart space is a region of the real world that is extensively equipped with sensors, actuators and computing components". The problem of this definition, viewed today, lies in the fact that it is incomplete, because the "intelligent factor" disappears, as the definition only considers hardware components. Due to that, in 2002, other authors decide to propose their own definition. [1] defines a Smart Environment as "a system that is able to autonomously acquire and apply knowledge about the environment and adapt to its inhabitants' preferences and requirements in order to improve their experience". This second option, however, is unspecific. Although it explains the expected operation way (from a high level point of view), including the human factor and not including any reference to hardware or software elements, makes difficult to determine when a system agrees with the definition and when not.

So much so that, in 2005, the same authors in [5] proposed a new definition: "A smart environment is a physical world that is interconnected through a continuous network abundantly and invisibly with sensors, actuators and computational units, embedded seamlessly in the everyday objects of our lives". This last definition, much more complex, was endorsed by other authors, such as the famous KITECH (Korea Institute of Industrial Technology), nevertheless, as in the first case; this definition does not include any reference to the "intelligent part" of the system.

From 2010, more or less, the interest on these systems decrease, and researches abandon attempts to formalize the theoretical framework. At this moment, a new concept captures all interest: the Cyber-Physical Systems (CPS). The most popular definition, presented in [10], defines the CPS as "integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa."

In 2010, hardware infrastructure for ubiquitous systems has started maturing, what allows defining CPS from a more behavioral and specific point of view. However, although any future attempt must apply CPS's principles, this name also groups systems that are "not enough smart" (for example, as we said, in 2002 it became clear that smart systems have to "adapt to its inhabitants' preferences and requirements").

In order to join the CPS's principles with all previous knowledge, we define the Smart Adaptable Cyber-Physical Systems (SACPS).

A Smart Adaptable Cyber-Physical Systems (SACPS) is a physical world that is interconnected through a continuous network abundantly and invisibly with sensors, actuators and computational units, embedded seamlessly in the everyday objects and/or clothes. The resulting system must be monitored from a control process management entity, and must define feedback loops where information and collected data from sensors affect physical processes. The system must be adaptable to different domains and be oriented to prosumer user, for which must implement self-configuration and dynamic self-adaptation capabilities.

In this definition, as we can see, all aspects previously seen are present:

The first definition's part refers the communications physical infrastructure and its relation with the external world. As can be seen, it is really similar to the definition proposed in [5] for the "Smart Environments", to which a reference to the modern wearable technologies has been added.

The second part, in relation with process control and feedback loops, is directly related with the work philosophy in CPS (orient to process, Big Data, etc.).

The third and last part (relative to system self-configuration and its adaptation to prosumer user) gathers the necessity (showed in [1]) to make the system autonomous and adaptable to the users' preferences and requirements.

3 Elements in a SACPS Layered Model

All SACPS are parts of the physical world, which connects with the rest of the reality through a permeable interface that allows the transference of materials, objects, energy, user, etc. (see Fig. 1(a)).

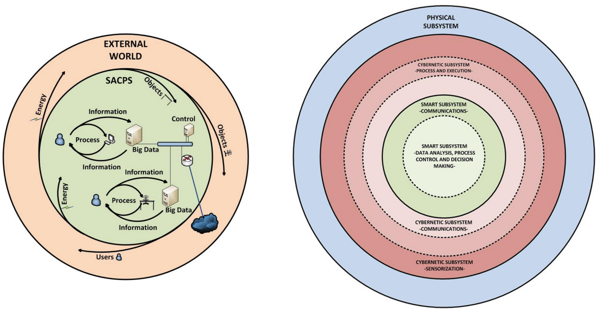

Fig. 1. (a) Relation between the external world and a SACPS. (b) Layered model of a generic SACPS

However, despite they can be considered as a unit, inside each SACPS various subsystems can be distinguished. Each subsystem will encapsulate some elements and functions from the complete systems. Namely:

Physical subsystem: It includes all the elements from the ordinary world that are part of the SACPS, but which they have not been modified to include any electronic instrument, communication device or process element. This subsystem also includes the power supply, the physical space occupied by the system and all the information stored in several variables, own the physical world (temperature, blood pressure…). Here are also integrated all users that take advantage of the SACPS's services, but which are not experts neither in the system's technology base nor in its specific application field. In what follows, we will name as "habitants" to this kind of users.

Cybernetic subsystem: It includes all the elements from the ordinary world that have been modified in some way, in order to integrate (seamless) electronic instrumental, communication devices and/or process elements. Smart furniture, wearables or any other similar device (we will call "cybernetic devices" to them) belong to this subsystem. This subsystem is, besides, in charge of monitoring the physical subsystem and acting over it. Cybernetic devices, at the same time, can be made of up to three different modules: sensorisation module, process and execution module, and communications module. Sensorisation module includes all electronic instrumentation and the device's actuators, such as displays, LED, etc. Process and execution module includes, if there was one, the device's microcontroller unit and all its peripherals. This part is in charge of executing the task ordered from the smart subsystem, controlling sensors and actuators, executing micro-services, etc. Finally, communications module includes all the infrastructure and software, necessary to allow the communication among the cybernetic devices, and between the device and the smart. Depending on how many modules implements a cybernetic device; we can distinct three classes of devices:

- Tagged cybernetic device: We use this name with devices that only implement the communications module. Furthermore, that module can only communicate with other cybernetic devices with which link connection will be available (never with the smart subsystem). The amount of information which can communicate is, besides, limited. The employed terminology comes from RFID technology, where this kind of modules is called "tag RFID".
- Peripheral cybernetic device: These devices implement the sensorisation module and a reduce functions communications module. Because these devices do not have a complete communications module, they only can communicate with other cybernetic devices with which link connection exits. This time, however, there are not limitations in the amount of transmittable data.
- Full cybernetic device: Finally, devices of this group implement the three possible modules (with full functions). These devices, typically, will receive information from their sensors and from close peripheral devices and tagged objects. With this information it will execute the delegated task, and will inform to the smart subsystem if it were necessary.

Smart subsystem: It includes all the infrastructure, applications, software, and management systems which controls and monitorizes the other subsystems, processes received data and feedbacks future process with the information extracted from these data. It can be divided in other two subsystems: communications subsystem (that makes possible the information flow with the cybernetic subsystem) and data analysis, process control and decision making subsystem. Here, besides, it will be implemented the politics that will allow the self-configuration and dynamic self-adaptation of the SACPS. This subsystem, moreover, includes those users which are not experts in the SACPS's base technology, but they are experts in the system's application field (prosumer users). These users, as can act directly over the smart subsystem, so that they can adjust the global behavior of the SACPS to their requirements.

It is usual in this kind of technologies (see [10]) representing the system as a set of concentric layers, where as you progress inward, you get way from the physical world. Then, the layered model for a generic SACPS can be expressed as in Fig. 1(b).

4 Classification of SACPS

Within the set of SACPS several classifications can be made: depending on the application field, depending on the number of elements, etc. The nature of the main data source considered differentiates all SACPS in these three categories:

Actor-focused systems: These systems are totally oriented to obtain data from SACPS's habitants. The interest is focused on how the users behave and what they feel. Due to the nature of these systems, it is indispensable that data sampling, processing, and decision making to be at real-time and execute in high-speed (with the purpose of supplying feedback as soon as possible). Of course, this does not impede, in addition, other systems for data analysis to be included. From an electronic point of view, these systems are extensively equipped with biometrical sensors and wearable devices (see Fig. 2); all of them powered in an independent and continuous way, in order to guarantee a permanent access to users' data. Systems thought for helping in some types of rehabilitation, or labor stress detection, are some of the applications of the SACPS of this category.

Object-focused systems: In these systems the interest is focused on the interactions among the devices which make up the SACPS. In these systems, moreover, habitants

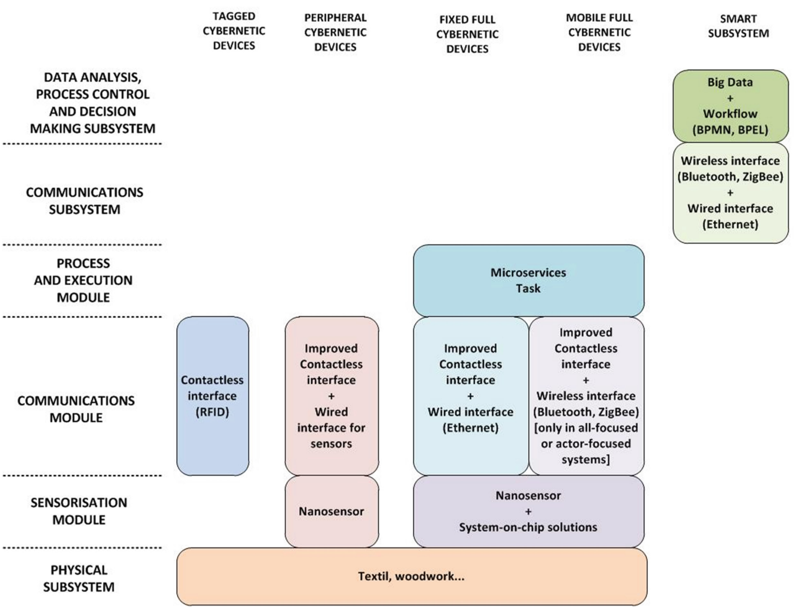

Fig. 2. Base technologies employed in SACPSs

become elements with the same importance, and at the same level, than furniture, objects. Applications deployed in this type of systems do not demand, in general, a continuous data supply, so data sampling can be based on collection-stored-delivery schemes. Furthermore, at hardware level, a more relaxed scheme of data sampling allows the extensive use of communication systems where one of the extremes is passive (see Fig. 2). Traceability systems, control process and stock management, are typical application examples that belong to this group of SACPS.

All-focused systems: These systems are really complex, as they integrate both visions from the previous groups. On the one hand, they implement applications typical to the object-focused systems, where habitants and object are treated in the same way. On the other hand, the information provided by the actor-focused systems is also necessary here, so user monitoring infrastructure must be included. At electronic level, they are systems really similar to actor-focused ones, although, at application level, they implement (besides) functionalities typical from object-focused systems. It is a really useful point of view in systems destined to critical or dangerous resources management such as explosives or toxic gases. In these situations, knowing infrastructure information (stock, etc.) is as important as knowing actor information (i.e. the biological state of worker that manipulate the material).

References

1. Das, S.K., Cook, D.J.: The role of prediction algorithms in the MavHome smart home architecture. IEEE Wirel. Commun. **9**(6), 77–84 (2002)
2. Das, S.K., Cook, D.J.: Agent based health monitoring in smart homes. In: Proceedings of the International. Conference on Smart Homes and Health Telematics (ICOST), Singapore, Sept 2004. Keynote Talk
3. Le Gal, C., Martin, J., Lux, A., Crowley, J.L.: Smart office: design of an intelligent environment. IEEE Intell. Syst. **16**(4), 60–66 (2001)
4. Lesser, E.: The intelligent home testbed. In: Proceedings Of Autonomy Control Software Workshop, Jan 1999
5. Das, S.K., Cook, D.J.: Smart Environments: Technology, Protocols, and Applications. Wiley, Chichester (2005)
6. Youngblood M., Cook D.J., Holder L.B.: Managing adaptive versatile environments. In: Proceedings of IEEE International Conference on Pervasive Computing and Communications, pp. 351–360 (2005)
7. Fox, A., Johanson, B., Hanrahan, P., Winograd, T.: Integrating information appliances into an interactive space. IEEE Comput. Graphics Appl. **20**(3), 54–65 (2000)
8. Srivastava M.B.: Smart Kindergarten: sensor-based wireless networks for smart problem-solving environments. In: Proceedings ACM Conference on Mobile Computing and Networking (2001)
9. Nixon, P., Dobson, S., Lacey, G.: Managing smart environments. In: Proceedings of the Workshop on Software Engineering for Wearable and Pervasive Computing, June 2000
10. Lee, E.: Cyber physical systems: design challenges. In: Proceedings on 11th IEEE International Symposium on Object Oriented Real-Time Distributed Computing (ISORC), pp. 363–369 (2008)