Interaction with a personalised smart space to enhance people everyday life

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Abstract. In the last years the interest for designing and implementing smart spaces grew significantly. Many researches adopted a top-down approach, focusing on embedding smartness in buildings, objects and everyday artefacts. In my research work I propose a shift in the point of view and suggest the adoption of a user-centred design approach. This will lead to a new definition of smart spaces based on people needs and requirements and in which smartness is related to the capability of creating a personalised space that enables a deeper and emotional bond between an individual and the space itself. The main goal of my work is to propose a new interaction paradigm supporting natural and spontaneous ways of exchanging information between people and their surroundings. A further aim is the definition of a framework to support the construction of a personalised smart space.

1 Introduction

The concept of smart space describes a physical place where people and technologies cohabit and continuously exchange information in order to create a hybrid and interactive space where people's requests are satisfied in an intelligent way. Starting from this definition, I focus on the importance of space in people everyday life. There are several studies that highlight how human beings establish a deep relation with the physical environment in which they live and how, in turn, the environment influences the creation of their own identities and their personalities [51]. The author claims that a space can be better defined taking into account a set of human values related to their everyday life and experience in the space itself.

Bringing these considerations one step further, Augé [5] [4] identified two kinds of places: "non-place" and "place". On the one hand, he defines "non-places" those that are transient, i.e., those where people only transit such as airports or train stations. On the other hand, he identifies a "place" as the one where people become active subjects of an event. Being part of a place stimulates the creation of an emotional bond and, in general, a relationship based on exchanging of information and feelings with what is occurring in that specific place (when I use the term "space" in the following, I will refer to this latter notion) [20] [14]. Introducing technologies in everyday environments

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makes it harder to maintain these relationships. In particular, researchers showed that in everyday life technology stresses the distance between people and their surroundings and reduces people to people interactions, introducing distraction [41], mediation [18] and overload of information [11] in the relationships between people and the surroundings. In particular, the overload of information and events that characterise any environment with pervasive technologies blurs the bond between people and spaces. [21], stressing the distance between virtual and real spaces, remarks that the establishment of an authentic experience between people and space around them becomes more difficult.

All these researches adopted a top-down approach, focusing on embedding smartness in buildings, objects and everyday artefacts. In my research work I propose a shift in the point of view and suggest the adoption of a user-centred design approach. This will lead to a new definition of smart spaces based on people needs and requirements and in which smartness is related to the capability of creating a personalised space that enables a deeper and emotional bond between an individual and the space itself.

Starting from these considerations, the research question leading my work is: *What make a space smart?* To answer this question, I will adopt the following approach:

- In order to define what a smart space (SMA) is, I will introduce a notion of "level of granularity" for smartness (intelligence). Such a level depends on the set of smart objects and on the people that cohabit in the space and that cooperate in order to define its smartness. In this sense a smart space is an aggregation of different smart elements such as people and objects and can be seen as a sort of composite smart object. I envision a new kind of personalised smart space, (PSMA), specific for each individual and based on the individual's experience and features.
- I will focus on humans and their body as the most relevant elements defining the environment around us. The body can be considered as a natural interface to keep in contact with the surroundings; moreover, human senses are useful means to explore the environment, building knowledge about it and to create a strong bridge between the external world and internal status.
- I will characterise "Smart Physical Objects" (SPOs) as innovative components in the environment. They are physical objects enhanced with sensing and/or processing capabilities that are able to react to external stimuli, yet preserving their physical properties.

In this perspective, context-awareness is the first issue to be addressed for defining a smart space [22] as a proactive environment, able to change and reply to customised demands of the human beings populating it.

The main aim of this work is to characterise a PSMA as a an entity where human bodies, SMAs and SPOs create a real interaction network which can increase the quality of people everyday life according to the needs, preferences and requirements of each human being that lives inside it. In order to design such a complex customised system, I will focus on redefining the way in which these components keep in contact with each other.

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Taking inspiration from the concept of a sentient multimedia system [10], where some degree of intelligence and self-adaptation according to the end users characterise the space as *alive* and *intelligent*, this work goes one step on towards the collaboration between people and SPOs. In fact, the collaboration between them represents an issue in order to enrich everyday life to establish emotional and meaningful bonds between people and their surroundings, bypassing any boundaries of communication and interaction.

The paper is organised as follow: Section 2 provides a definition of the main components of my approach (human bodies, SPOs, SMAs), describing separately each one of them and then recomposing them to characterise a PSMA. Section 3, adopting a user centred approach, describes the methodological steps to follow in order to define a PSMA. Section 4 describes the research carried on, the results achieved so far and the expected contributions of my thesis. In the Table 1, a list of acronyms adopted in this paper.

Acronym	**Full Name**	**Example**
SPO	Smart Physical Object	Smart Board
SMA	Smart Space	Smart Classroom
PSMA	Personalised Smart Space	Personalised Smart Classroom

Table 1: List of acronyms

2 Pillars

In order to define a PSMA I will start by analysing its main components. A PSMA is the setting where a plethora of different intelligent components with various capabilities and levels of smartness live and cooperate, a complex system created by the interrelation of people, places and objects. I will adopt a methodological approach based on two main steps:

1. I will provide a definition of smart space (SMA), including different levels of granularity of smartness for the space and its components;
2. I will adopt a user centred approach to define a PSMA as a personalised place where people find a simple and natural way to get a response to their needs.

In order to achieve a PSMA, one requires a combination of context-awareness and personalisation. Objects may be enhanced by different aspects of context awareness to sense context attributes affecting the users present and to take appropriate action where this is necessary [43]. On the other hand personalisation components may be responsible for creating and managing user preference information and applying it where necessary. In this schema, I will focus on the role of the body as the main component that enables an innovative interface through which people can exchange information with surroundings. In the following, I will describe the three main components of a PSMA.

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2.1 Body

Taking inspiration from the roman architect Vitruvius, the body can be considered as a referent to construct adapted spaces and buildings [35]. Designing the Vitruvian Man, Leonardo da Vinci suggested to adopt the human body as a measure of everything (e.g., inch and feet units in the imperial system), using the proportions of the body as instruments to identify a space that is best suited for humans. Leonardo's studies about the body were important also for his mechanical inventions that were all designed around the human body. As a result, these works underlined the importance of the human body as the most relevant element to define the surroundings. They showed that the body represents also a main component in the process to manage and organise the environment: people define coordinates and orientation completely related to their body.

Moreover, the human body already presents a set of *special tools* for interacting with the environment: the human senses [34]. Human experience starts with them: touching, smelling, hearing, tasting, seeing, exploring the environment with the senses, building knowledge about it. According to the theories of embodied cognition and embodied space [26], knowledge derives from the coupling of *action* and *perception*, exploiting the experiences generated by the continuous interactions between the body and the environment [13]. The body operates as a *framer of information* [16] because only through the body users can receive and send messages, manage and store information, track some parameters, and decide what they want and what they do not want to know about the context around them. The body controls all kinds of information. Thus, the role of the body in the space is doubled: on the one hand, it represents the way to interpret reality; on the other hand, it activates the display of information about itself. Finally, the body becomes a bridge across which the ambiguity of boundaries between "real" and "virtual" can be overcome. The "digitally empowered" human body allows users to control information overload, making it possible for them to navigate, consume and grasp the spirit of a place and thus build one's own identity Nowadays, there is an increasing interest in rediscovering bodies [16], senses [47] and gestures[19] in order to achieve new interaction models to experience the surrounding environment.

2.2 Space

Traditionally, there are several ways to describe a space. On the one hand, a space is considered as an empty area between things. On the other hand, other approaches focus on defining space as the distance from other people or things that a person needs in order to remain comfortable [1] [45]. In my view, I would like to consider a space as a composite place, where people, objects and physical space cohabit.

Currently, an SMA is defined as a place enhanced with digital capabilities. Embedded sensors collaborate in order to perceive information in the context. Actuators perform different actions according to the contextual situation around them. The ultimate goal is to transform the space to be able to reply to users'

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requirements. Although researchers focused on implementing these notions, there is a lack of a theoretical characterisation of what a space is and what makes it smart.

Following Dourish [14], the definition of smart space can be seen as a process in which both technology and collaboration are critical elements. On the one hand, space is a collective product; it is an outcome of shared forms of practice and meaning-making. On the other, technologies of all sorts represent means through which we define the space [32]. The increasing of recent technological developments provide us the opportunities to re-encounter and re-imagine everyday space. As a consequence, Cabitza et al. [10] support the emergence of a *sentient multimedia system*, where some degree of intelligence and self-adaptation according to the end users characterise the space as *alive* and *intelligent*.

Bringing one step further the considerations about human body and space in Section 2.1, I can analyse the role that human body covers in defining the space. The human represents the main component in the process to describe and organise the surrounding environment.

Stressing the importance of the bond that people can establish with the space where they live and exploiting body as the main element to keep in contact with the environment, I intend to reach an innovative definition of SMA based on the perceptions of space from user-centred perspective, taking into account the potentiality that human have to interact in a SMA. In the following, I will refer to this notion as Personalised Smart Space (PSMA).

2.3 Objects

Objects, and more in general, artefacts represent instruments designed to accomplish a general or a specific task: they can be better defined looking at the actions that people can achieve through them [48]. For this reason, I can consider as objects also cognitive artefacts, without any necessary physical properties [36]. Thus I will consider not only physical objects, but also a set of processes, rules and procedures that allow people to perform an interaction with environment.

The main role of an object is allowing an extension of human capabilities, improving and/or augmenting her common abilities [49]. Looking to a concrete example, the hammer represents an extension of the human arm, giving to individuals a stronger and more powerful capability to use it.

A second role of an object is to embody what people can do with it [17] [37], as an interface that enables actions and usages according to the affordances that it offers.

Currently, there is a growing interest in making objects able to see, hear, and smell the physical world and in allowing them to connect to exchange information with the surroundings [24]. Going towards the *Ubiquitous Computing paradigm* [54] and Internet of Things (IoT) era, smart physical objects (SPOs) are able to act in the environment and to connect to the Internet, benefiting of the plethora of services and information that Internet can offer. In this way they can receive inputs from the world (using sensors) and produce outputs into the world (using actuators). Also, SPOs need to have digital identities and to be context-aware

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for interacting with each others [2] and to provide a set of affordances that enable to use them [31].

As a result, one can see an SPO as the combination of two main components [7]: a physical layer including a controller and a set of sensors, actuators and communication capabilities and a digital layer that enables to manage their behaviour in the context of use. Consequently, starting from a common artefact, it is possible to make it an SPO, introducing computational power and interactive capabilities [33] into it. SPOs can be characterised by different levels of smartness: from the ability to communicate with people and other smart objects, to the ability of managing knowledge about themselves, their role, scope and relation in the surrounding environment [6] to the ability of learning from experience. One of the output of this project is to provide a classification of the granularity of smartness of SPOs according to their capabilities [44].

3 Goal and methodological approach

The main goal is to define the novel concept of PSMA as a complex system where human body and SPOs cohabit in a shared experienced space with a continuous exchange of information, collaboration and negotiation between them according to the needs of each individual. Using a user-centred approach, I intend to support the idea that not only is a PSMA defined by the intelligence embedded in it, but it is especially characterised by the capability to adapt in order to accomplish the individual needs, preferences, requirements of each single user, becoming her personal PSMA, able to reflect her personal experiences.

In order to characterise a PSMA and to introduce new paradigms of interaction with it, I will take two different methodological steps.

1. I will characterise a PSMA as an SPO, or better as a composite SPO, in which the combination of SPOs with different levels of intelligence gives it an higher level of intelligence and responsiveness to users' needs, according to the presence of humans.
2. Adopting user-centered design, my focus would be on people who would play a central role in the process of defining the intelligence of the space. Human body would be used as an interface and human senses would be the principal instruments for exploration of the space.

3.1 First step

Defining smartness In order to characterise smartness in a space, I need a classification of smartness in objects. An SPO is a combination of a physical and a digital layer; the latter can be describe as a set of computational functionalities that enhance its abilities yet preserving its physical aspect. It can be considered as an enhanced tangible object proving augmented functionalities with respect to the original physical object.

Many dimensions can be taken into account in order to characterise intelligence in an SPO; these dimensions provide different abilities to the SPO. First

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of all, smartness can be regarded as the awareness about its roles and goals according to different contexts of use. Second, it is related to the ability to interact with humans and other SPOs that constitute the surroundings. Third it can be related to the ability of making inferences and of learning from experience. In summary it can be related to the interaction and problem solving capabilities of an SPO. The highest level of intelligence can be reached with the ability to change its behaviour according to contextual situation, supporting a continuous and active exchange of information and states between the SPO and its surrounding [23].

Having these principles in mind, I will start the analysis of what a SPO is to reach a more detailed definition of SPO based on the recognition of dimensions for intelligence. The final goal is to introduce a strong characterisation of SPOs describing their abilities and their problem solving capabilities in a contextual situations.

Coding the smart space language Given the characterisation of SPOs, I will characterise an SMA as a composite SPO, whose intelligence derives from the aggregation of the level of intelligence of the composing objects. I expect that the level of intelligence of the SPO is more than the aggregation of its components, also for the presence of humans that makes it a more complex system than an object.

I expect the following main results. First, I will provide for designer a framework for describing how a SMA can be obtained taking into account each component that could be inside it and the minimum level of smartness that it should have in order to be active and proactive with the surroundings. Second, I will provide for people an innovative paradigm allowing interaction in a smart space. Combining gestures and body languages and space represents a difficult research activity because I need to establish a connection between human languages and spatial configurations in order to achieve formal specifications of their relations [50] [8] [25]. The main idea is to create a coding of space components (objects, space, people) in order to define a framework to represent SMA and to support the communication between the components in it and the negotiation of their actions.

3.2 Second step

In the second step, I will focus on human beings and their interaction with the surroundings. As already explained in Section 2.1, a PSMA can be characterised as complex customised system capable of reshaping and modifying itself for responding to the personal demands of each single individual.

In order to achieve this goal, I intend:

- To take into account user's needs in order to transform a SMA into a PSMA able to respond to them;
- To design a new interaction paradigm that allows users to exchange needs and information with the environment in a more natural and spontaneous way.

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Mapping user's needs In order to map the user's needs, I will borrow techniques from user adaptive ubiquitous systems that are able to adapt their behaviour and interaction based on user's features and the context. These systems rely on representations of users (User Models) [9] that can provide a complete picture of each user with her features, habits, preferences, behaviours and activities. Exploiting these models, they can support the selection of a set of appropriate services adapted to the user's features.

A PSMA can result from the combination of user modeling and adaptation technologies with the functionalities offered by a SMA. As a result, a PSMA model will be built aggregating data from the user and correlating them with data about the SMA and SPOs, in order to provide services personalised to user's features (preferences, needs, habits, goals), place features and SPOs.

Designing a new interaction paradigm between people and spaces The emergence of a PSMA able to know, understand, and predict user's needs, preferences and requests, allow people to interact with it without any additional effort. The *Ubiquitous Computing paradigm* [54] a nd IoT era allow us to put computational capabilities and digital information in the environment and give us continuous and seamless access to them [32]. Starting from the desktop paradigm and moving toward to mobile ones, we can observe a constant improvement of the user experience without a real involvement of the user's body experience. A set of simple body movements is needed in order to interact with different objects, such as one-finger swipe gestures and taps [52] [3]. However, most of these interactions require a reduced usage of our sensorimotor abilities [42].

Bypassing the traditional interaction model (Fig. 1), the increasing adoption of wearable technologies opens new opportunities, offering an interaction with surrounding spaces that needs a minimal effort from the users. In fact, wearable computing allows us to use our own body to get in touch with the environment. As a consequence, the body plays the role of an innovative interface to exchange information with a large variety of personal devices and the environment.

Bringing these considerations one step further, there is a growing of interest in designing new natural interaction models, using gestural interaction and, more generally, a *body in action* according to the embodied cognition theory and its applications [53]. The exploitation of the richness of the body, of the senses and of the movements considers actions as the most relevant part of cognition [13]. As a result, the growth of studies about full-body interaction restores the importance of the human body as a controller able to move with several degrees of freedom and, at the same time, as an interface to exchange information with the surrounding environment.

New frontiers in multi-sensory digital experiences appeared first time in 1962 with Heilig's Sensorama [46]; nevertheless, the attention to human senses is still limited [47]. The interest for senses such as smell and taste, usually ignored in the past, is growing. The aim of multimodal interaction is to exploit the human ability to process more than one interaction modality at the same time [15]. As an instance, Obrist recently investigated the design space of three interaction modalities still mostly unexplored for HCI, smell [40], taste [38], and touch [39].

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As a result, there is a huge space of new perspectives for the design of ubiquitous natural interaction exploiting the human body and senses, taking inspiration from the matching between the capabilities offered by innovative technologies such as wearable computing, tangible interfaces and the renewed interest in body and senses (Fig. 2).

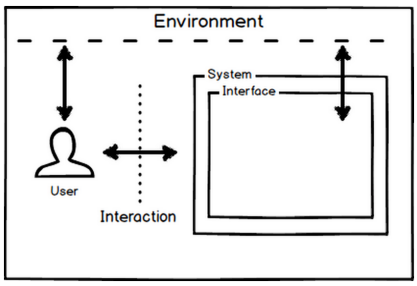

Fig. 1: Traditional interaction

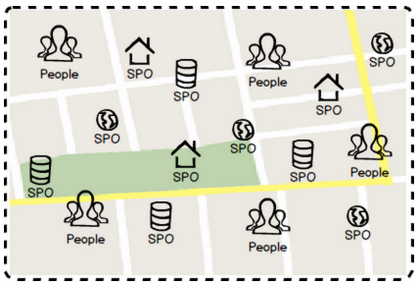

Fig. 2: Interaction in PSMA

4 Expected results and future steps

Combining the relevant perspectives discussed in the previous sections, the main aim of my work is twofold: first, selecting and using new interactive tools that stimulate a natural interaction in the spaces allowing a continuous exchange of information between people and a SMA in order to create a PSMA; second, finding a new interaction paradigm to support a direct interaction with spaces exploiting human body as a natural interface and adopting gesture and human senses as the only tools to accomplish these tasks. In fact, Figure 1 illustrates a traditional model of interactions between human, environment and technologies through an interface. The interface between them represents the interactions between these domains connecting the real world with the digital world and allowing an exchange of information between them. The environment is a key component at the common intersection of these interactions.

Going beyond the traditional way to describe interaction using an interface as a mediator in order to allow people to manage digital layer manipulating just the physical one (Fig. 1), Figures 2 describes the interaction in a PSMA based on a new paradigm as a language to exchange information in user-friendly way with the environment (Fig. 2). The constant exchange between descriptions of people derived from user model and capabilities and knowledge embedded in an SMA will allow us to build a new concept of PSMA completely based on the user features, needs and preferences, without any mediation in interaction [12]. Access to these large source of personal data allows to interpret them differently according to a range of contextual parameters. These parameters provides an indication of the emotional context of the particular person involved. This will allow people to interact using their body in a more spontaneous way and allow each one of them to build her own PSMA [27].

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In overall, with the proposed study, I expect I will be able to answer our research questions about the relation between body and space, and how it can be enhanced in the Ubiquitous era thanks to the potentialities offered by the body to interact with spaces.

Taking inspiration from the steps already defined in Section 2, the ultimate goal will be the definition of a spatial framework based on these components and able to provide a set of instruments and guidelines to build a PSMA starting from the definition of the space itself.

The current status of my research project is as follows:

- I analysed what a SPO is and in particular how intelligence can be characterised, decomposing it into several dimensions[28]. I then introduced new affordances to communicate the augmented functionalities of SPOs [31].
- I introduced natural interaction paradigms for spaces, focusing on wearable computing [30], full body experience and multisensory experience [29].

Next steps will be toward understanding new frontiers in natural interaction in spaces through body and gestures. Moreover, I intend to map the users' needs in a user model that enables to build a PSMA based on their features, preferences and needs.

My PhD project is supervised by Luca Console, Full Professor of Computer Science at University di Torino.

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