Smart Spaces in Ubiquitous Computing

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ABSTRACT

In this era where development of Smart Spaces is an appealing goal in different disciplines, understanding its use in the context of Ubiquitous Computing is essential for its' comprehensive exploration. Although the term 'Smart Spaces' has been frequently used by the Ubiquitous Computing research community, there is a gap between its use and the underlying principles of Ubiquitous Computing. The majority of researchers focus their research on providing information rich environments and ignore the need to continuously support computational tasks and resources within the space. This paper explores the different principles and characteristics of Ubiquitous Computing and analyses a variety of Smart Space research. The paper identifies the key components and attributes of a true Smart Space and provides a definition of Smart Spaces in the context of Ubiquitous Computing.

Keywords: Smart Spaces, Intelligent agents, User Mobility, Ubiquitous Computing and Reasoning Mechanism.

1. Introduction

Current developments in technologies and infrastructures for Ubiquitous Computing (Ubicomp) have motivated the invention of different applications that are becoming highly useful in human life. The state-of-the-art of these inventions is the development of environments that understand and react to human desires, *Smart Spaces*. These environments are useful in areas from entertainment to work optimisation and to assisting elderly and disabled people.

Although many research communities have leveraged Ubicomp benefits to develop so called Smart Spaces, the definition for Smart Spaces meaning is quite vague. Many researchers focus on providing an information rich environment that ignore user mobility within the space. User mobility involves providing continuous access to computational tasks and resources within these environments. Such vague and incomplete definition of the term Smart Spaces fails to fully identify the potential of Ubicomp for supporting and improving daily life of individuals. Furthermore, it brings about confusion to novices in the Ubicomp research community and individuals outside the Ubicomp community.

Therefore, a better understanding of Smart Spaces in the context of Ubicomp is the cornerstone for the growth of research in Smart Spaces in Ubicomp. In this paper we present and review Smart Spaces in the context of Ubicomp and propose a formal definition for Smart

Spaces. This is useful to both researchers in Ubicomp to further explore the support of Smart Spaces in our daily life, and for novices understand the characteristics and definition of Smart Spaces in the context of Ubicomp.

The rest of this paper has been organised as follows: Section 2 provides a review of Ubicomp focusing on key aspects of Ubicomp environments. Section 3 explores general views of Smart Spaces as applied by the Ubicomp research community. Section 4 provides characteristics and the working definition of Smart Spaces in Ubicomp. Section 5 presents summary of the paper.

2. Background of Ubicomp

The root of Ubicomp can be traced back to 1991 when, the late, Mark Weiser wrote his visionary article about the 3rd generation of computing, *Ubiquitous Computing* as opposed to 1st generation, mainframe, and 2nd generation personal computers. This 3rd generation aims to minimise human interaction and integrate computing devices into the environment [1]. Ubiquitous means *being everywhere* [2], however, explaining Ubicomp in this way limits its underlying meaning. It is therefore necessary to describe it based on two perspectives; computing *being hidden* and *everywhere*.

In this paper we argue that the underlying goal of Ubicomp is to support humans in their everyday activities. To achieve this goal appropriate *ubiquitous technologies* [1] need to be used and new applications need to be implemented to leverage these technologies [3]. By ubiquitous technologies we mean devices that support simple user interaction, location tracking, recognition systems and interactive displays to provide information.

Ubicomp has evolved in three phases; *proliferation of computing devices, natural interface* development and *application-centred* research [3], as in figure 1. The initial phase is characterised by computing devices which are of different size, particularly miniaturised, and most importantly capable of knowing their locations [1, 4]. Network infrastructures to support interconnection of these devices was a core element of this research [1]. The work performed by Want et al [4] on integrating palm-sized computer into an office network is a compelling demonstration of this research.

Unfortunately, these technologies did not work well with traditional keyboard and mouse input technologies, and demand for intuitive user interaction devices was still pressing [3]. This led to a new shift of Ubicomp research, *natural interfaces* that focus on human speech, gestures and movement. Ubicomp research considered capturing these natural actions using custom built Ubicomp devices. The development of Pen-based input device is a good example of this research [5].

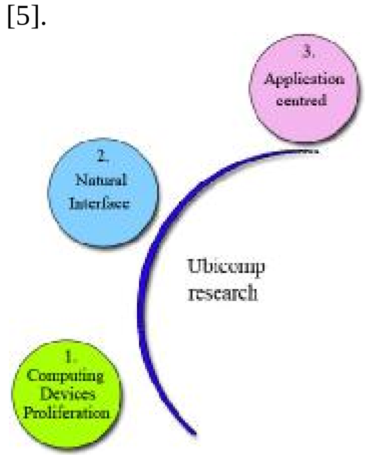

Figure 1: Evolution of Ubicomp research

The third phase, which we are currently in, is research on designing and developing of infrastructure and applications to leverage existing and novel ubiquitous technologies. Abowd and Mynatt [3] refer to this phase as *application-centred* research. Its main focus is to better support everyday tasks and observe the effect Ubicomp has to our life. The effort invested in the Cyberguide application [6] can exemplify this research. It is this theme of *better supporting* our life that has driven the focus on implicit user inputs. The emergence of context-aware applications, automatic capture and access reflect the emphasis in this research [3].

2.1 Ubicomp environments

These are environments saturated with computing devices embedded in everyday objects that gracefully integrate with human activity [7, 8]. Such smart objects include interactive whiteboards, tables and smart walls that we can interact with. These environments are characterised by many sensors that perceive the physical environment [9]. Unlike other computational spaces, Ubicomp environments tend to be highly dynamic and heterogeneous [10].

2.1.1 Sample Environment

"An employee wants to show a set of figures to his manager. As he approaches her office, a quick glance at his tab confirms that the boss is in and alone. In the midst of their conversation, the employee uses the tab to locate the data file on the network server and to request a printout. The system sends his request by default to the closest printer and notifies him when the job is finished." [4]

This *employee-figure* scenario depicts what it is like being in a Ubicomp environment. Services move with the user without requiring any interactions, *hidden computing everywhere*.

Three elements are fundamental in this environment; Ubicomp devices, sensors and network infrastructure [4]. Ubicomp devices can be compact, mobile and provide functionality that were previously difficult to support in 1st and 2nd generation computing. The employee's palm-sized mobile computer, referred as *tab*, exemplify these devices, as in figure 2.

Figure 2: Palm-sized mobile computer

Additionally, sensors are mandatory to perceive the current state of the physical environment. This perception, referred to as *context* [11], is an important aspect understanding the environment. In the *employee-figure* scenario above, context includes the unique identity of the user and devices around him, and the location of the user. Although much research has been done on *context* [11, 12], its discussion is beyond the scope of this paper.

2.1.2 Mobility in Ubicomp

Mobility is an integral part of our everyday life, and so Ubicomp environments must support mobility [7]. By mobility we mean the ability to support users' computational needs while moving from one point to another. These needs cover both computational tasks and resource availability [13]. The ability of an environment to route whatever the user was working on from his desktop computer to his Smartphone is an example of supporting user mobility. To achieve this, an appropriate network infrastructure is required. This supports continual interaction of a user with wirelessly interconnected computing devices within the Ubicomp environment [1].

As Ubicomp focuses on minimising manual human interaction and integrating computing devices into the environment, the provision of seamless connectivity is an important attribute [14] of a Ubicomp environment. For example consider a mobile phone, and the number of cellular base stations it automatically connects to, disconnects from in each day to ensure continuous service? This is a difficult task and would require significant time and effort. Likewise in Ubicomp environments, services should follow the users whenever they go within network range of a Ubicomp environment without demanding user interactions.

Although the *employee-figure* scenario illustrates the look-and-feel of Ubicomp environments, a Smart Space provides enhanced functionality. In a Smart Space scenario the employee should not have to be near his manager's office for notification as to whether she is in or else. Moreover, the employee should not require to manually search for data files. In other words, a Smart Space should understand the context of the physical environment and the users needs and be ready to act on user's behalf.

3. Smart Spaces: General Views

Research in Ubicomp has advanced significantly and what seemed to be impossible a decade ago is now feasible. The development of highly distributed environments that feature thousands of invisible devices and sensors is among the achievements of Ubicomp [9]. Although many applications have been built as a result of Ubicomp research, the focus of this paper is limited to so called Smart Spaces.

At a very high abstract level, Smart Spaces can be regarded as an Ubicomp environment that understands and reacts to human desires. The research into these environments is motivated by continual miniaturisation of computing devices and the possibility of augmenting humans' everyday tasks [15]. Moreover, the possibility of converging Ubicomp technologies with machine learning techniques have boosted the research interest in Smart Spaces [16].

Unlike Ubicomp environments, Smart Spaces incorporate processes to make the environment smart. These processes can be categorised as *bottom-up* and *top-down* cycle [17]. Where the sensors monitor and collect physical information in a bottom up process and decisions are made by the r*easoning mechanism* and the resulting action is implemented in a top-down manner.

While many researchers in Ubicomp have defined Smart Spaces, table 1, there remains a gap between these definitions and basic Ubicomp principle of user mobility support. Also the majority of these definitions overlook the necessity of Smart Spaces to understand and reason about the environment as a whole. In effect, these environments are much like the work of Mozer [18] on building a self-learning smart environments, ACHE, which primarily focussed on intelligent automation of home appliances.

Definition	**Comments**
Sentient, information-rich environment that sense and react to situational information to tailor themselves to meet users' expectations and preferences [9].	Its degree of intelligence is only limited to individual intelligent agent and not an environment as a whole.
A well-defined area that is embedded with computing infrastructure that enables sensing and controlling of the physical environment [7].	It does emphasise on the need to proactively act on user's behalf and assist their mobility in this environment.
A region of the real world that is extensively equipped with sensors, actuators and computing components [19].	It does not involve intelligence and mobility which are significant elements for Smart Spaces in Ubicomp.
An environment stipulated by intelligent agents, services, devices, and sensors to provide relevant services and information to meeting participants on the basis of their contexts [12].	It partially supports user mobility. It only depends on centralised computation routing.
An environment that acts as an intelligent agent that perceives and acts on the environment through sensors and actuators to reason about and adapt to its inhabitants [20].	Although MavHome project involves some sort of intelligence to predict users' mobility, their focus is only limited on centralised computational routing.
An assistive environment that can sense itself and its residents and enact mappings between the physical world and remote monitoring and intervention services [21].	The key attribute of this environment is the ability to change its state.
"Work environments with embedded computers, information appliances, and multi-modal sensors allowing people to perform tasks efficiently by offering unprecedented levels of access to information and assistance from computers" [22].	Although this definition clearly shows the underlying meaning of mobility in Ubicomp, it ignores the need of demonstrating intelligence in these environments.

Table 1: Definitions of Smart Spaces

Consider for instance, based on the definition proposed by Satyanarayanan [7], that any Ubicomp environment can be regarded as a Smart Space. The definitions proposed by Al-Muhtadi [9] and Nixon [19] demonstrates some degree of intelligence, their reasoning capability is only limited to individual intelligent devices, such as a CoffeeMaker. This limits the flexibility of utilising other devices that are within the environment.

Smart Spaces tend to be saturated with many heterogeneous computing devices and sensors. Therefore a generic environmental reasoning mechanism becomes important in order to mediate between these devices and provide decisions that proactively support human desires.

As support for user mobility is among the basic principle characteristics of Ubicomp, it is inappropriate to build a Smart Space in Ubicomp without accommodating this aspect.

Based on this fact, the definitions proposed by Nixon [19], Chen [12], Youngblood [23], Helal [21] and Rosenthal [22] would not fully qualify as definitions of Smart Spaces in the context of Ubicomp. These definitions and their usage are limited to changing the state of the environment and providing a convenient way of utilising resources, but they ignore the need to continuously supporting users within their perimeters.

In this paper, we contend that most of the Smart Space research is based on intelligent automation of devices to support their inhabitants and not true Smart Spaces in Ubicomp. These environments do not provide true integration of devices with support for mobility. In effect, they provide limited support for continuous access to computational tasks and resources for their inhabitants. For example the research in Gator Tech [21] and MavHouse [20] is similar in concept to the ACHE [18] work, even though they differ in technology and approaches.

4. Smart Spaces in Ubicomp

Ubicomp environments are open and dynamic, and above all support for user mobility is a basic principle and crucial. Therefore, Smart Spaces in Ubicomp need to be both predictive and highly integrated to take advantage of the nearest devices to support what we refer as a *true user mobility*. By true user mobility we mean the ability of an environment to continuously provide access to computational tasks and resources anywhere and everywhere in that environment.

4.1 Attributes of Smart Spaces

To reflect the basic principles and concepts underlying Ubicomp, we argue that Smart Spaces in the context of Ubicomp must have four components; *Ubicomp devices*, *wireless networks*, *sensors* and *reasoning mechanism*, as in figure 3, and support user mobility. Although many of these components have been used in previous incomplete definitions, in this paper we emphasise their capabilities in the support of true user mobility.

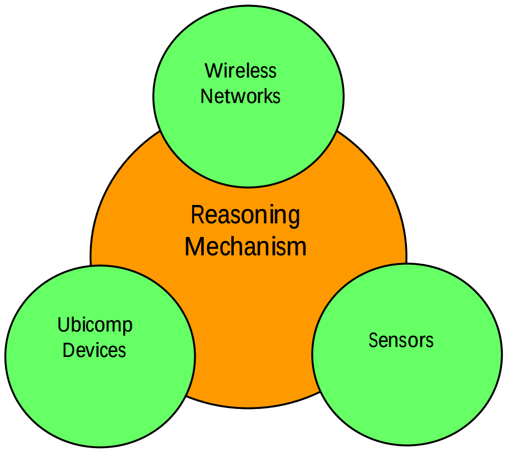

Figure 3: Components of Smart Spaces

4.1.1 Ubicomp devices

Ubicomp devices go beyond desktop computing to perform tasks that were previously difficult. There are many devices that have a range of sizes and costs that allow them to be everywhere and almost be invisible [1, 4]. The employees' palm-sized mobile computer, shown in figure 2, is an example of such a device. Ubicomp devices support both intuitive user interactions and user mobility.

4.1.2 Wireless networks

Ubicomp environments are saturated with computing devices and sensors that are interconnected with wireless networks. Wireless networks in Smart Spaces facilitate integration of computing devices, support user mobility and facilitate the integration of sensors to form *sensor networks*. It is these sensor networks that are responsible for acquiring and distributing information from individual sensors to a reasoning mechanism in Smart Spaces [17]. Collecting situational information, *context-awareness*, is a key attribute of Smart Spaces provided by sensors..

4.1.3 Sensors

Sensors can be widely defined as a physical device that augments the physical sensing of the environment [24]. Based on this definition, audio microphones and video cameras are regarded as sensors. Smart sensors can go further to include limited reasoning of the sensed information [17]. Sensors provide real-time data about the environment that allows it to effectively react to user's desires. Regardless of their capabilities, sensors, when connected with a wireless network, enable Smart Spaces to model and communicate the current state of the physical environment to the reasoning mechanism.

4.1.4 Reasoning mechanism

Smart Spaces need to be highly integrated with sensory and computing devices. This means that these environments collect vast amounts of information on a daily basis. In order to fully utilise this information, Smart Spaces must deploy reasoning mechanisms to filter and manage the information. The role of reasoning mechanism is twofold; modelling the collected information into abstracted useful knowledge, and reasoning with this knowledge to effectively support users' daily activities [17].

4.1.5 User Mobility

In addition to these elements Smart Spaces in Ubicomp must support true user mobility within the confined environment of Ubicomp and seamlessly integrate computing devices that provide transparent and intuitive user interaction. Most of the reviewed research have fulfilled the latter aspect, the former, mobility, is still elusive. The majority of research is limited to the view of providing information rich environments. That is their focus is to effectively provide information to their inhabitants and ignore the aspect of mobility of users by supporting the mobility of computational tasks.

4.2 Smart Space: Definition

For a Smart Space in Ubicomp we identify the key components as Ubicomp devices, wireless networks, sensors and reasoning mechanism. In addition we identify the need to support true user mobility to fully define a Smart Space in Ubicomp. From these components and the true user mobility attribute we propose the following definition for a Smart Space in Ubicomp as;

"*A highly integrated computing and sensory environment that effectively reasons about the physical and user context of the space to transparently act on human desires*"

By *highly integrated* we mean an environment that is saturated with Ubicomp devices and sensors that are fully integrated with wireless networks; by *effectively reason* we mean a pseudo-intelligent reasoning mechanism for the environment as a whole, not just to an individual device or component; by *user context* we refer to an individuals profiles, policies, current location and mobility status; finally by *transparently act* we mean an environment that is responsive to human and supports their mobility without requiring user interaction.

5. Conclusion

Smart Spaces have been widely researched in Ubiquitous Computing, though there is no consistent definition for a Smart Space.

In the context of Ubicomp the definition of a Smart Space should adhere to the underlying explicit and implicit characteristics and principles of Ubicomp as defined by Weiser [1].

In this paper we have identified the basic principles and characteristics of Ubicomp and critically analysed research that claims to be Smart Space research. We have also characterised Smart Spaces in the context of ubiquitous computing

We have proposed a novel definition for Smart Spaces in ubiquitous computing context. Smart Spaces are essentially enhanced ubiquitous computing environments that have pseudo-intelligent mechanisms to support reasoning and predictive responses to users.

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