The Wrong Challenge of ‘Pervasive Computing’: The Paradigm of Sensor-Based Context-Awareness

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Abstract. This paper is concerned with providing a critical reflexion about Weiser’s vision implementation of what is supposed to appear as the new era of human computer interaction: Ubiquitous computing. The aim of this paper is not a review of the concept of Pervasive computing which is commonly, and at its advantage called Ubiquitous computing. Nor an unarguable inventory of contentions in favor of Pervasiveness or not. On contrary, this paper acknowledges a certain idea of inobtrusive interaction mobility but emits reserves of the means for realizing this vision. This paper encourages and challenges modestly the mobile computing community for adopting and reformulating new research directions for supporting Weiser’s vision.

1 Introduction

For most of us, interacting with computers has been mainly stationary. This is now changing in a big way. In fact, and on a different scale computation is moving beyond personal devices. With the advent of ever smaller, lighter, faster artifacts along with various sensing technologies, computation becomes embedded in everyday devices and free us of the single desk. Also wireless technology allows devices to be fully interconnected with the electronic world. The technology mentioned above offer many challenges for designers. In reality, these technologies move the site and style of interaction beyond the desktop and into a larger world where we live and act. If for designers, the desktop appears to be well-understood, the real world, however is complex and dynamic. The design challenge, then is to make computation useful in various situations that can be encountered in the real world. Then appears another difficulty : the issue of context or context-aware computing which is utterly controversial for a number of reseachers [1996], [1998]. What is a technology which is context-aware? Discussion of context and context-awareness suffers from the generality of the concept. A context-aware application is basically a technology which is able to sense the

situation in which it is immersed and adjust its actions appropriately. When humans talk, they use a wide range of mimics (e.g. body languages) to express their ideas according to the spatial environment they are located. Both gestural and physical location have for goal and advantage to increase their 'conversational bandwidth' [2000]. Unfortunately, this human to human interaction does not apply quite well when humans interact with computers. By improving access to contextualisation, designers will make communication much more efficient in human-computer interaction and finally produce more useful computational services. If the goal of context-aware computing is to make human-computer interaction easier, then how context should be provided to computers? How to better take advantage of the physical space to render the human-computer interaction more efficient and intelligible? Additionally, the increase of mobility creates situations where the user's context, such as the location of a user and the people and objects around him, is more dynamic. As a natural advancement of wireless telecommunications capabilities, open networks, and continued increases in computing power have given the users the expectation that they can access information services whenever and wherever they are.

This paper addresses the quality of the reliability of sensor-based context recognition through the wireless spectrum in the effective use of human-computer interaction.

The first section describes the contribution of sensor acquisition to context-awareness. To gain context information the usage of sensors is proposed. The description of this contribution is extended and classified according to its respective application domain. This includes an analysis and discussion of the technical feasibility of context acquisition in a general context of computing mobility.

The second section considers the field of inquiry of the notion of sensing context and analyses commentaries that this reflection has raised in the literature. Finally, from a technical perspective a representative sample of important issues is enumerated and discussed. A general motivation and recurrent question underlying this paper is how Weiser's vision (e.g. the ideal case) could reasonably be implemented by means of current technologies.

2 The Contribution of Sensor Acquisition to Context-Awareness

The actual utility of context-awareness in mobile systems has been demonstrated in a wide range of application examples [2000], [1999], as well as in indoors [2002], [2005] and outdoors [2002], [2001] environment. If context is the rationale, what constitutes context and how context could be captured, processed, and exploited for providing sustained added value and positive experiences to the end-user?

In this section, we explore several procedures for sensing the environment. Towards this goal, we illustrate context acquisition through relatives applications. Finally, issues and contribution of the sensor technology relevant to context acquisition are discussed.

2.1 Context Processing

Context-Awareness

Predicting and Approximating. The use of sensor¹ data for context implementation consists of predicting or anticipating and finally approximating situations resulting from real world situations with respective consideration of context categorization and available sensing technologies.

The Ideas of Capturing Data. Sensing devices allow systems to have information about real world context data such as location of people, things and other artifacts in the spatial environment. In order to offer additional functionalities and to improve HCI² for mobile devices and appliances, research and literature have considered three major areas of interest to support these needs:

1. Sensor infrastructure

This approach (e.g indirect awareness [2002]) allows the dissemination of multitude of sensors spread across a geographical area for obtaining and providing context to smart devices. Practical examples of such technology are various. Wireless ad hoc sensor network figures among this technology.

2. Sensor integration

A more recent approach has fostered the idea that diverse sensors and several extraction techniques should be merged to alleviate the problems caused by complex algorithms and expensive hardware to simple sensors. This approach relies more on mobile terminal capabilities rather than on infrastructure. Examples of such technology (e.g the Smart-Its [2001]) are few as regard to their indirect counterpart.

3. Derived context

A modern approach (e.g derived context) has consisting of involving applications which make deductions from contextual data.

Cue Generation

The Machine Learning Mechanism. Appropriate sensor selection coupling with a typical machine learning mechanism offer a positive approach for extracting and deriving raw from sensor data. Conceptually, the signal detection method and the cue extraction algorithms, employed in a situational context, are similar to any A/D Converter³ used in Digital Signal Processing. As a result, the relationship between cues and context help to forecast plausible scenarios resulting from cues' description, and finally allowing artifacts for taking appropriate actions according to the user's location.

Cue Attribute Extractions. Context appears to be more closely related to the person's or the object's location whereas cues are assumed to be more generic.

¹ A sensor is a device that produces a measurable response to a change in a physical condition such as temperature or in a chemical condition such as concentration.

² Human-Computer Interaction.

³ Analog-to-Digital Converter used to convert an analog signal into a digital format.

Towards this goal, the TEA⁴ project [1998] has contributed in understanding of how multi-sensor context-awareness can be applied in mobile computing for the benefit of capturing context. The outcome of the research activity suggested that in a practical context recognition, results based on a single sensor may in many cases be unreliable. Realibility of recognition can be enhanced by fusing the features from many different sources [2003]. Analysis of this contribution to sensor based perception of real-world scenarios corroborates several aspects of perception findings in TEA project:

- Perception findings
 1. Useful context appears to be beyond location. As a result, additional information could be derived from it.
 2. Single powerful sensor architecture emphasizes location (e.g position) because it captures only restrictive aspects of environment. Multiple sensors architecture (e.g collection of diverse simple sensors) emphasizes context because it takes advantage of various specific aspects of the environment which gives an overall picture that better characterizes situation (e.g context) than location.
 3. On contrary of sensor fusion (e.g diverse sensors), the fusion of diverse sensors, as an approach to derive context improves perception. The goal is to improve accuracy and precision by integrating multiple type of similar sensors.

From Smart Sensor Objects to Wireless Sensor Networks. The basic and primary used of sensors was consisting in embedding sensors in the object itself, along with memory, power supply and wireless networking capability. The object then can communicate details about how it is being used. By continuously connecting a variety of sensors through short-range wireless connections, sensors networks take sensor technology beyond the capabilities of individual smart objects to an integrated component within a larger system. As a result, each sensor has wireless communication capability and some level of intelligence for signal processing and networking of the data.

2.2 Contribution of Sensing Technology to Location Aware Computing

Location: A Key Part of Context-Awareness

The Usefulness of Location Sevicees. Determining a mobile user’s current location with accuracy will be one of the most important functions of future mobile computing environments. Besides, many different technologies exist that provide location for both outdoor and indoor environments [2002], [2001]. Location

⁴ Technology for Enabling Awareness is a joint project of the University of Karlsruhe, Nokia Mobile Phones, Starlab N.V. and Omega Generation funded under ESPRIT programme of the European Commission’s Fourth Framework as part of the call Esprit for IT Mobility. For further information see <http://tea.starlab.net/>.

information is a critical attribute of context information for context-aware applications used by mobile users. Location services take many forms and provide value in a diversity of ways, but the common denominator is the spatial data handling capability that links location to other types of data. Simply knowing where a mobile user is, or how far the mobile user is from someone or something, is typically not valuable by itself. Relating location to other pertinent information gives its meaning and value. This information is eventually used to provision the user more valuable services based on the user profile such as: personalized news, guidance services, and other relevant services.

Broadly, one of the greatest potential for sensor-based context-awareness consists of enhancing the user experience by minimising the active user effort needed in managing the local environment.

We gave an analysis of available sensing technologies for acquiring information from the user and the environment to facilitate HCI. We have also enlightened sensor capabilities perception techniques used for capturing environment. Moreover, discussions of sensor integration have shown that distributed sensors is an exemplary approach to capture real world situations and to fairly adjust HCI. Equally important, experimental results have showed that the concept provides a technical viable solution for providing significant benefits for user of mobile appliances. Context is fine in theory. Still, sensor integration with localization services for larger scales remains an open issue. Research on sensor-based context-awareness is purely theoretical and does not address the difficulties of implementation and evaluation in real use. As a result, a number of challenges still need to be addressed.

3 The Resulting 'Pervasiveness Controversy': Towards a Sensor Revolution?

As a solution for enhancing the user experience, multi-sensor awareness technology envisions a world in which almost every object will be able to sense, reason, communicate and act, adapted to the relevant context. From this point of view, Pervasiveness and Ubiquitous computing do not escape from this proliferation of sensors in our everyday lives. However, research activities have suggested that large networks of interconnected smart sensors should be implemented to better monitor and control our world for realizing Weiser's vision. As a prerequisite towards a sensor revolution in a pervasive environment, it belongs to the research community to wonder how to collate and correlate the sensor information and provide it in a useful way to any smart device.

3.1 The Controversy

One of the main leaders in the controversial issue raised not by the concept itself, rather by its application is Thomas Erickson ⁵. Erickson wishes that applications could adjust their actions appropriately in the context in which they

⁵ A research staff member at IBM T.J. Watson Research Center, Hawthorne, NY.

are immersed. In fact, he feels reserved about the implementation success of such technology that he calls 'metaphor'. [2002]

Issues

The Controversy. In fact, Erickson considers that we, as human beings integrate a broad range of values such as habits, manners, behaviors, dispositions, capacities and so on. The addition of all these qualities are empirically what he calls common sense. From this point of view, mankind with common sense would notice when being at the opera or theater that he should turn his handset in silent mode for instance. He does not deny that the application will be able to detect the motionless location of the user, nor the dark place with ambient noise. Consequently and by comparison, he deduces that the context-awareness of the human being and the one of any application are very different from each other. One is qualitatively characterized by empirism whereas the other is quantitatively characterized by sensors which have moreover the ability to detect and respond to a small range of features of their surroundings.

His Arguments. He really feels sceptical about the implementation success of such technology as regard as to the following reason :

- The prevailing argument consists of the ability of any application to be able to recognize the context and take appropriate action. According to him, this capability requires 'considerable intelligence'. He considers that if one day, the human being is able to implement a robust context-aware application which will rarely fail, that necessarily supposes the addition of new rules. We all know, based on experience that new set of rules increases complexity. The ultimate consequence is to make the application more difficult to understand. Interacting in a new and unfamiliar manner makes the interaction inaccessible and complicated. It seems that mankind has not learnt yet from his previous experiences. The case of Artificial Intelligence is a good example in its attempt of implementing complex systems or applications that require common sense. Current attempts in this direction have led to infuriate applications which fairly mimic mankind in a clumsy way. Nevertheless, from an era of needless technology, AI⁶ seems to head for a more helpful technology. As a result, we should not be misleading by the goals of the two entities. This technology should not be used in this direction.

Computational systems are good at gathering and aggregating data; humans are good at recognizing contexts and determining what is appropriate. [2002]

3.2 Context Sensing

Key Issues and Challenges Associated with Sensors. Although there are many examples of smart sensor objects technologies achieving technical

⁶ Artificial Intelligence.

goals [2001], [2001]. There are also too many examples of smart sensor devices development projects not achieving technical goals [2003], [2001]. However difficulties arise when creating a sensor network:

Scalability. Large number of mostly stationary sensors are necessary to capture the dynamic and rich semantic of any physical environment. To provide context-awareness to smart devices, networks of 10,000 or even 100,000 nodes are envisioned, so scalability is a major issue. So far, no densely sensor networks have not been deployed yet in the real world. It likely happens in the near future and these for two main reasons:

1. No universally accepted standards exist to enable massive and inexpensive implementation of wireless sensor networks. This issue is related with intellectual property ownership among manufacturers. Several standards have been proposed and are currently under development including the IEEE 1451 series [1998] and many others [1999]. These approaches provide standards for connecting sensors and actuators to networks.
2. The second issue concerns major technology barriers that in some instances limit the technology implementation of network sensors. These issues are described below.

Increased Volumes of Data. Wireless sensor networks will result in an explosive increase in data flows as networks become more pervasive. This will in turn raise a series of issues about how to deal with all the data or cues [2002]. New data and storage management methods and techniques will be needed.

RFID Embeddeness and Privacy Issues. In an Ubiquitous computing system, all items of interest (e.g bag, purse) must be individually tagged. In fact, RFID enables electronic labeling and wireless identification of objects using radio frequency communications. Especially as the technology gets smaller and smaller, an embedded RFID tag becomes potentially hard to find and difficult to remove. Moreover, the embeddeness of RFID tag could broadcast information without the knowledge of the mobile user when passing a scanner. Therefore, the public's reaction to a network system that can track almost any artifact could possibly be an obstacle.

Cost. Factors empeding the adoption of sensors are cost. It is very important to justify the overall cost of the network. Due to mass production techniques, sensor cost has noticeably decreased. Still, the cost of a single sensor remains a very challenging issue when considering the deployment of distributed sensor nodes.

Power Supply. Sensor nodes are limited in power, computational capacities and available storage capacity. Since in many applications sensor nodes will be placed in a remote area, service of a node may not be possible. In this context, lifetime of a node may be determined by the battery life, thereby requiring the minimization of energy expenditure. Altogether, with the proposed size limitations (e.g tiny and integratable into the environment), battery power alone does not suffice to ensure self-containment.

New Applications. Despite all the shortcomings mentioned above, doubtless that technologies for distributed sensor network will generate new breakthroughs.

1. Sensor will be smaller and more cost effective as a module.
2. Wireless technologies speed will increase with low latency and integrated in more reliable and larger network infrastructure.
3. Altogether, new competences and new skills will emerge for implementing and managing the sensor technology.

We have described real wireless applications of smart sensor device technologies with significant and economic feasibility concerns. The sum of issues makes sensor a fairly ordinary medium with the result that the sensor revolution creates more shortcomings to overcome than profitable solutions for end users. It is assumed that with the use of many sensors and the combination of different kinds of sensors (e.g sensor fusion) a large degree of awareness could be achieved. Still, experimental results have shown that sensor technology partly fails to capture some level of details inherent to the physical space. Sensor fusion captures only limited awareness information. [2001]

4 Conclusion

The broad aim of this paper was to argue the challenging and following question: 'How mobility while balancing with embedded computing can and should be integrated to capture the rich semantic of the physical space in such way that both permeate our environment?' Obviously, no absolute and definitive answer could be stated at this early implementation stage of pervasiveness. Each new technology provides increased benefits. Certainly, any new technology offers the potential to make life easier and more enjoyable. So do Pervasive computing and Ubiquitous computing, in their respective vision to improve the quality of life by creating the desired atmosphere and functionality via intelligent, personalized interconnected systems and services. As noted above, the implementation technology raises more issues than solutions.

For instance, one important issue for context-aware applications is that they must model the physical environment through an appropriate location model. However, no device is able to capture the rich, dynamic and semantic context due to its heterogeneous aspect. Mobile appliances can only recognize some aspects of context. To achieve true context awareness, mobile artifacts need to produce infallible real-world context data in the presence of uncertainty irrespective of location. The challenge, then for contextualisation applications will be to determine which parts of available context resources are relevant.

However many obstacles stand in the way before we can know where an object is all the time using sensor technologies due to the inadequacy of the tracking performance. Therefore creating an efficient and accurate sensing positioning system for indoor environment is a challenging task.

At the last, there is somekind of paradox in which sensor technology might be desirable from the perspective of network interface features, yet the economic

and technical viability may make sensors undesirable. Sensor-based context-awareness is limited by the technology available. Hence, to deal with the challenges outlined above, realization of Weiser's vision will require:

1. Investigating innovative sensing approaches using various sensors and algorithms.
2. To mature the theory of distributed sensor network systems enough (see section 3.2), further research is needed.
3. Bringing a large number of disciplines together.

Only when we have achieved this degree of interoperability will Weiser's vision become a reality.

Nevertheless, the future will be collaborative...

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