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Survey

Urban pervasive applications: Challenges, scenarios and case studies☆

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ABSTRACT

In this work, we discuss various aspects of the application of pervasive technologies inside an urban setting. In the last decade we have seen the emergence of a multitude of closely-related pervasive technologies that have only recently started to materialize on a grand scale, such as wireless sensor networks, RFID and NFC. We discuss the arising research challenges associated with such converging fields and we also provide a survey of the state-of-the-art related application scenaria, which we believe set their near-future applied context. Finally, we provide a more analytic discussion on three discrete systems that belong to this category of applications and give insight to the current state-of-the-art work in this field.

1. Introduction

In the last few years we have been witnessing a rapidly growing trend towards the interconnection of the digital and physical domains, as is also evidenced by the outstanding activity in the wireless sensor networking research area and the continuous integration of sensing devices in multiple application domains. We are continuously looking for additional ways of better monitoring our environment, and also of ways for interfacing ourselves and our activities to the computing infrastructure. Other closely-related technologies such as NFC and RFID are also gaining momentum and are integrated in various sets of applications further backing this vision. Although lots of different names are being used to describe neighboring research fields, e.g., wireless sensor networks, ubiquitous computing, physical computing, etc., we argue that under specific assumptions and application contexts, they can all be placed under a *pervasive computing* label. That is, the unobtrusive integration of such technologies in our everyday lives.

Currently, the pervasive deployment of tiny devices with minimum storage and limited or no computational capabilities appears a realistic perspective; sensor networks are becoming quite common, e.g., in home automation. Also, the major obstacle of the strict energy constraints of battery-powered devices is tackled with passive devices (i.e., not powered by batteries) that have simultaneously emerged in the

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last decade, the most prominent examples being RFID and NFC tags. An RFID tag is an object that can be attached to or incorporated into a product, animal, or person for the purpose of identification and tracking using radio waves. There is a number of RFID classes, ranging from completely passive to active tags; passive RFID tags have no internal power supply, whereas active ones can have more power and processing capabilities, somehow similar to sensor network nodes. Near Field Communication (NFC), is a short-range high-frequency wireless communication technology which enables the exchange of data between devices within a short distance. An NFC device is compatible with existing RFID infrastructures and is primarily aimed at usage in mobile phones. Plenty of applications are foreseen: mobile ticketing in public transport, mobile payment, smart posters, bluetooth pairing and smart-posters. The combination of such vastly deployed technologies creates a framework in which pervasive computing can make further progress.

One could go as far as arguing that even the recent trends of using touch screens and motion to control devices like mobile phones and gaming consoles reflect this paradigm shift (i.e., the interconnection of the physical and digital domains) to a certain degree. Even smartphones nowadays carry a multitude of sensors, which can be harnessed along with the aforementioned technologies to bring into life new exciting applications. We have certainly come a long way from the first days of sensor networking measuring temperature, light and humidity inside university buildings, to the point that it may seem that we have changed the problem we are trying to solve. Wireless sensor networking hardware (e.g., the Arduino platform [1]), is used today in architecture schools to study interactivity. However, as Albert Einstein once humorously put it, "...if we knew what it was we were doing, it would not be called research, would it?".

Regarding applications, although a multitude of them has been proposed in both urban and rural contexts, the latter seem to be greatly surpassed by the former, both in number and applicability. This is related on the one hand on their closely-coupled hardware and software, i.e., such systems are usually specific-purpose, and to the simple fact of the difficulty in their deployment and management. Thus far, we have only a few examples of large-scale deployments of such systems, whereas in the case of urban deployments we are currently seeing great advances, as signified by research projects such as CitySense [2] and SmartSantander EU research project (starting in 2010). Such large-scale projects utilize a big infrastructure based on the technologies discussed here in order to offer a range of services. It is our belief that urban pervasive applications set the framework for providing useful and meaningful services to a wide spectrum of end-users.

Furthermore, when discussing applications inside an urban pervasive setting, one should also take into account one major event in the last decade: the rise of social networking. We are producing and consuming information with evermore increasing numbers and ways, and the integration of sensing devices, which brings together the digital and the natural worlds, seems only natural. The rise of a new data-producing culture can already be seen just by the number of platforms available for publishing sports, biking, hiking data, which seems to indicate that many people are already familiar with such concepts. For a discussion of user-driven sensing data acquisition, see [3]. A term often used to describe this specific data-production trend is *crowdsourcing*, derived from "crowd" and "outsourcing" [4].

In this paper we first survey the current state-of-the-art and discuss a number of application scenaria, in order to showcase a number of specific research challenges, the applicability of this type of applications/systems and the associated implementation issues. We then identify the major research challenges associated with pervasive applications set in an urban context. Finally, we discuss in more detail three discrete systems, utilizing sensor networks, RFID and NFC, that provide an insight regarding the applicability of the aforementioned concepts in the context of social networking, gaming and smart posters.

2. Application scenaria

In this section, we focus on three diverse categories of application scenaria, that have drawn the attention of the research and other communities, the last few years: participatory sensing, pervasive gaming and collective intelligence. These three fields enclose a number of subgenres, and although they have not reached yet a critical mass of users worldwide, they seem to be slowly finding their way to the mainstream, especially with regard to the mobile phone applications available.

2.1. *Urban/participatory sensing*

The increasing sensing capabilities found in consumer devices such as cell phones or audio/video players, can be exploited for the deployment of very large scale urban sensing activities [5–7,3]. A range of related application scenaria can be seen on [8]. One interesting feature in this category of applications is that apart from the Computer Science and Electrical Engineering research communities, it has sparked a certain interest from architects, civil engineers or even artists (e.g., [9,10]).

There are two general approaches in this context so far: the first one includes the use of a certain sensing infrastructure in order to get measurements, albeit using small devices scattered in large numbers in an urban setting, whereas the second one is based mostly on a voluntary user basis. Of course there is also overlap between these two extremes in many situations. This design consideration is mostly affected by the nature of the services provided by the systems and their target. Community-driven projects tend to rely solely on end-users, while end-services-providing systems, where organizations like the ones that telecommunication providers offer, prefer infrastructure-based architectures.

Architectural design considerations in this context also include: the methods of sensed data collection, analysis, verification, and sharing; and respecting the privacy and anonymity concerns of the people involved. Nevertheless, including consumer devices implies that the human owners of these devices play an important role in the resulting system's architecture and consequently it is important to understand to what extent they should be conscious active participants