Panos Markopoulos
Berry Eggen
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James L. Crowley (Eds.)

LNCS 3295

Ambient Intelligence

Second European Symposium, EUSAI 2004
Eindhoven, The Netherlands, November 2004
Proceedings

Springer

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Second European Symposium, EUSAI 2004
Eindhoven, The Netherlands, November 8-11, 2004
Proceedings

Springer

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Library of Congress Control Number: 2004114340

CR Subject Classification (1998): H.4, H.5, D.2, C.2, C.3, I.3, K.4, I.2

ISSN 0302-9743
ISBN 3-540-23721-6 Springer Berlin Heidelberg New York

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Printed in Germany

Typesetting: Camera-ready by author, data conversion by PTP-Berlin, Protago-TeX-Production GmbH
Printed on acid-free paper SPIN: 11342090 06/3142 5 4 3 2 1 0

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Preface

This volume of the LNCS is the formal proceedings of the 2nd European Symposium on Ambient Intelligence, EUSAI 2004. This event was held on November 8–10, 2004 at the Eindhoven University of Technology, in Eindhoven, the Netherlands.

EUSAI 2004 followed a successful first event in 2003, organized by Philips Research. This turned out to be a timely initiative that created a forum for bringing together European researchers, working on different disciplines all contributing towards the human-centric technological vision of ambient intelligence. Compared to conferences working on similar and overlapping fields, the first EUSAI was characterized by a strong industrial focus reflected in the program committee and the content of the program. As program chairs of EUSAI 2004 we tried to preserve the character for this event and its combined focus on the four major thematic areas: ubiquitous computing, context awareness, intelligence, and natural interaction. Further, we tried to make EUSAI 2004 grow into a full-fledged double-track conference, with surrounding events like tutorials and specialized workshops, a poster and demonstration exhibition and a student design competition. The conference program included three invited keynotes, Ted Selker from MIT, Tom Rodden from the University of Nottingham and Tom Erickson from IBM.

Out of 90 paper submissions received for the conference, 36 were selected for inclusion in this volume. Papers were submitted anonymously and 3–5 anonymous reviewers reviewed each. The review committee included experts from each of the four thematic areas mentioned above representing both academia and industry. The four program co-chairs made the final selection of papers for the proceedings. In this process, special attention was devoted to divergent reviews that arose from the multidisciplinary nature of this emerging field. We are very confident of the rigor and high standard of this review process that safeguarded the quality of the final proceedings and ensured fairness to the contributing authors.

The papers in this volume are clustered into four groups:

- ubiquitous computing: software architectures, communication and distribution,
- context sensing and machine perception,
- algorithms and ontologies for learning and adaptation,
- human computer interaction in ambient intelligence.

We hope the result of this collective effort shall be rewarding for readers. We wish to thank all authors who submitted their articles to EUSAI and especially the authors of the selected papers for their efforts in improving their papers according to the reviews they received in preparation of this volume. We thank the members of the review committee for their hard work and expert input and especially for responding so well when their workload exceeded our original expectations.

We gratefully acknowledge the support by the JFS Schouten School for Research in User System Interaction, the Department of Industrial Design at TU/e, IOP-MMI Senter, the Royal Dutch Academy of Arts and Sciences (KNAW), Philips and Océ.

We wish to thank all those who supported the organization of EUSAI 2004 and who worked hard to make it a success. Specifically, we thank Harm van Essen, Elise van de Hoven, Evelien Perik, Natalia Romero, Andres Lucero and Franka van

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Neerven for their work and commitment in organizing, publicizing and running this event. We thank also the special category co-chairs Wijnand IJsselsteijn, Gerd Kortuem, Ian McClelland, Kristof van Laerhoven and Boris de Ruyter. We note here that an adjunct proceedings including extended abstracts for posters, tutorials, demonstrations and workshops was published separately.

Closing this preface, we wish to express our hope that this volume provides a useful reference for researchers in the field and that our efforts to make EUSAI 2004 possible contributed to the building of a community of researchers from industry and academia that will pursue research in the field of ambient intelligence.

Eindhoven
August 2004

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Super-distributed RFID Tag Infrastructures

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Abstract. With the emerging mass production of very small, cheap Radio Frequency Identification (RFID) tags, it is becoming feasible to deploy such tags on a large scale. In this paper, we advocate distribution schemes where passive RFID tags are deployed in vast quantities and in a highly redundant fashion over large areas or object surfaces. We show that such an approach opens up a whole spectrum of possibilities for creating novel RFID-based services and applications, including a new means of cooperation between mobile physical entities. We also discuss a number of challenges related to this approach, such as the density and structure of tag distributions, and tag typing and clustering. Finally, we outline two prototypical applications (a smart autonomous vacuum cleaner and a collaborative map-making system) and indicate future directions of research.

1 Introduction

In industry, the potential of radio frequency identification (RFID) technology was first recognized in the 1990s, stimulating the desire for RFID-supported applications such as product tracking, supply chain optimization, asset and tool management, and inventory and counterfeit control [22]. Besides these "conventional" application areas, passive RFID tags are also suited to augmenting physical objects with virtual representations or computational functionality, providing a versatile technology for "bridging physical and virtual worlds" in ubiquitous computing environments, as Want et al. showed [23].

Currently, the proliferation of RFID technology is advancing rapidly, while RFID reader devices, antennas and tags are becoming increasingly smaller and cheaper. As a result, the deployment of RFID technology on a larger scale is about to become both technically and economically feasible. Hitachi, for instance, is about to commence mass production of the *mu-chip* [11], which is a miniature RFID tag with a surface area of 0.3 mm^2. Further, the Auto-ID Center has proposed methods which could lower the cost per RFID chip to approx. five US cents [19].

In the conventional process of RFID tag deployment prevailing today, only a limited number of passive tags are placed in the environment in a deliberate and sparse fashion. Typically, RFID tags are mainly used for identifying objects [6,24] and for detecting the containedness relationships of these objects [14]. Explicitly placed stationary tags embedded in the environment also serve as dedicated artificial *landmarks*. They can be detected by means of a mobile RFID reader and are used to support the navigation of mobile devices and robots [13,16,17], or to mark places and passageways [10].

In this paper, we present the concept of *super-distributed RFID tag infrastructures,* which differs from the conventional means of RFID tag deployment and utilization. We

P. Markopoulos et al. (Eds.): EUSAI 2004, LNCS 3295, pp. 1–12, 2004.
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advocate *massively-redundant* tag distributions where cheap passive RFID tags (i.e. tags without a built-in power supply) are deployed in large quantities and in a highly redundant fashion over large areas or object surfaces. We show that, in so doing, the identity of a single tag becomes insignificant in exchange for an increased efficiency, coverage, and robustness of the infrastructure thus created as a whole. We further demonstrate that such an approach opens up a whole spectrum of possibilities for creating novel RFID-based services and location-dependent applications, including a new means of cooperation between mobile entities. We also discuss some of the technological opportunities and challenges, with the intention of stimulating further research in this area.

The remainder of the paper is organized as follows: In Section 2 we introduce the concept of super-distributed RFID-tag infrastructures and describe its particular qualities in detail. In Section 3, we discuss different means of deploying RFID tags efficiently and redundantly on a large scale. Then, in Section 4, we outline two prototypical applications (a smart autonomous vacuum cleaner and a collaborative map-making system) and indicate future directions of research.

2 Super-distributed RFID Tag Infrastructures

Passive RFID tags typically incorporate a miniature processing unit and a circuit for receiving power if the tag is brought within the field of an RFID reader. The tags are usually attached to mobile objects such as supermarket goods or other consumer products, and they send their identity to the reader over distances ranging from a few centimeters up to a few meters, depending on the type of tag.

RFID tags that are spread across a particular space in large redundant quantities can in turn be regarded as a "super-distributed" collection of tiny, immobile smart objects. The term "super-distribution" refers to the fact that a vast number of tags are involved, similar to the notion of "super-distributed objects" in [20]. Accordingly, we will refer to such a highly redundant tag distribution as a *super-distributed RFID tag infrastructure* (SDRI).

A highly redundant and dense distribution of tiny objects is also a common characteristic of wireless sensor networks which consist of a large number of very compact, autonomous sensor nodes. However, the two concepts differ fundamentally: in contrast to a fixed structure of independent and passive tags as part of an SDRI, wireless sensor networks are based on the "collaborative effort of a large number of nodes" [3]. Further, the topology of wireless sensor networks may change due to mobility on the part of its nodes. In addition, wireless sensor nodes carry their own power supply used to enable active sensing, data processing, and communication with other sensor nodes, whereas passive RFID tags only have very limited functionality, generally restricted to reading and writing a small amount of data. Also, compared to typical wireless sensor networks with nodes communicating over distances of tens of meters or more, mobile RFID antennas generally operate at a much shorter range.

By deploying an SDRI in an area, the overall physical space is divided into tagged and thus uniquely identifiable physical locations. This means that each tag can be used as an identifier for the precise location it covers, where coverage is pragmatically defined as the reading range of the tag. What we thus obtain can be described as an approximate

"discrete partitioning" of the physical space, of which different implementations are possible. If the tags of an SDRI are distributed according to a regular grid pattern, for example, then the partitioning of the physical space itself can be considered a physical grid of uniquely addressable cells approximating to the concept of a regular occupancy grid, as applied in the field of mobile robot navigation [7], for instance. If, on the other hand, the tags of the SDRI are distributed in a random fashion, we obtain an irregular pattern of uniquely addressable cells. Ideally, these cells are non-overlapping and cover the whole area. In practice, one can only approximate these properties.

In addition to the massive potential redundancy of RFID tags, two particularly interesting qualities of SDRIs are that they enable mobile devices to interact with their local physical environment, and that such an interaction can be performed in a highly distributed and concurrent manner. In the following, we explain these qualities in more detail.

2.1 Local Interaction with Physical Places

An SDRI allows mobile objects to store and retrieve data in the precise geographic location in which they are situated by writing to or reading from nearby RFID tags. Independent, anonymous entities are thus in a position to share knowledge and context information *in situ*.

One potential application of this quality is self-describing and self-announcing locations, where mobile devices can gain contextual or topological information on the spot simply by querying the local part of the RFID tag infrastructure. For instance, mobile GPS-enhanced vehicles could locally store positioning information while moving within an SDRI. Once a sufficiently large proportion of an affected area has thus been initialized, other mobile devices can be helped to recalibrate their GPS receivers, and GPS-less devices can be enabled to determine their position without using a dedicated positioning system themselves. Positional information stored in the SDRI can also be used to establish a fall-back service in case the primary positioning service is temporarily unavailable, thus increasing the overall availability of positional information in the area. Further, an SDRI facilitates the definition of arbitrary regions within physical spaces: virtual zones, barriers and markers can easily be defined by marking particular tags (or the tags along a border line) in the SDRI accordingly.

Furthermore, SDRIs in general offer *physical anchor points* which can serve as *entry points into virtual spaces* by allowing mobile devices to leave data traces, messages or links to virtual information (residing in a background infrastructure) wherever they roam. It is therefore possible to use the RFID tags of an SDRI as an alternative medium for implementing physical hyperlinks [12,18] in virtual spaces, or as a means of attaching virtual annotations [21] to physical places.

By providing a means for roaming mobile objects to anchor and thus persistently store location-dependent sensor information on the spot, SDRIs also constitute a self-sufficient alternative to services such as GeoWiki [8], where virtual information is linked to a geographical address, but which require explicit knowledge of the current geographic location or the continuous availability of a location service of a sufficiently high resolution and accuracy.

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