Sensor-based Context-Awareness for Situated Computing

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ABSTRACT

It can be argued that pervasive access to information and services becomes more valuable when they are related and adapted to the real world situations of their use. We discuss sensor-based approaches to awareness of such situations based on experience from two projects, one investigating context-awareness as add-on technology for mobile devices, and the other exploring the use of everyday things as context suppliers.

INTRODUCTION

Global and mobile networks make information and computer-based services available almost everywhere irrespective of location, embedded technologies let global information infrastructures stretch far into our everyday environments, and advances in information interfaces extend accessibility. Beyond the ultimate availability and accessibility an entirely new quality is added when information and services get related and adapted to the real world situations in which they are used. Situations of use have inherent locality, but there are many other aspects of situations that can serve as context for use of pervasive information.

Traditionally computer vision is applied to provide computer-based systems with perception of the surrounding real world. Advances in sensor technologies suggest alternative approaches to real world context acquisition based on embedded or body-worn sensor infrastructures. In this position paper we relate our experience with technologies for sensor-based context-awareness, and discuss concepts for an architecture that we envision as platform for context-aware systems.

EXPERIENCE WITH TECHNOLOGIES FOR CONTEXT-AWARENESS

We report on two projects we conducted over the last two years for exploration of sensor-based context-awareness. A fundamental idea underlying these projects is to use deliberately simple sensors and perception methods as opposed to expensive hardware and algorithms. Our approach start with the limited information obtained from individual sensors, and to achieve awareness of complex contexts through multi-sensor fusion, i.e. synthesis of features extracted from individual sensors. In comparison to computer vision it could be argued that this approach shifts complexity from algorithmic to architectural level. The underlying motivation however is to yield at a perception technology suitable for devices and appliances with limited computational and power resources.

TEA – Adding Context-Awareness to Mobile Devices

The TEA[1] project is concerned with adding awareness of surrounding usage situations to personal mobile devices based on the following concepts:

- Association of multi-sensor data with specific situations such as for instance *being in a meeting.*
- Integration of sensors and perception methods in an add-on component for mobile appliances that act as host device, for instance cellular phones and personal digital assistants.

The TEA system is based on a simple layered architecture that provides increasing levels of abstraction from sensors to adaptive application. The sensor layer is defined by an open array of sensors including both environmental sensors for perception of the real world and logical sensors for monitoring of conditions in the virtual world, for instance logical state of the host device. A second layer abstracts information from individual sensors to a number of so-called cues. The third layer provides for multi-sensor fusion based on synthesis of so-called contexts from cues. A fourth layer finally relates context to action to implement situated behavior.

To study feasibility of the TEA approach we implemented a hardware/software prototype with an array of different environment sensors and embedded perception techniques (statistical analysis and AI methods). The prototype was used in conjunction with a mobile phone for a scenario in which otherwise manual selection of usage profiles (such as

[1] TEA (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. For further information see http://tea.starlab.net/.

meeting, outdoors, in car etc, all with distinct notification and message forwarding behavior) was automated based on perceived context [4].

From the TEA feasibility study we gained relevant insights into design of sensor-based awareness technology, most importantly:

- Our study validated the two-step perception approach with feature extraction prior to fusion. A similar study is reported in [2]. Likewise, they recommended: "Don't forget to cook your sensors".
- In investigated "everyday situations" we found audio, light and acceleration sensors to be most relevant for context acquisition, while others such as temeprature and pressure contributed little or nothing.
- We realized placement of sensors has a large influence on performance. Tight packing of sensors as done in TEA compromises benefits that might be gained if sensors were placed in most appropriate positions on the body and connected via a body network to their host device.
- We found it makes sense to employ learning methods to improve context abstraction from available cues. This introduces the problematic issue of how to provide an interface between the TEA component and the user for feedback on performance of the awareness system.

MediaCup – Awareness Technology Embedded in Everyday Things

In another project on sensor-based context awareness we considered the use of ordinary things we use in our everyday activities as source of context information. In contrast to TEA the idea was to embedded awareness technology in everyday artifacts, to obtain context information from many such artifacts, and to make this context information generally available to applications. The model underlying this approach is:

- Artifacts have an awareness of their own local state
- Artifacts broadcast their state as context information into the surrounding information ecology
- Any application can process and use broadcast context information

For demonstration of this approach we created MediaCups which are ordinary coffee cups augmented with sensors, processing, and short-range communication in a proximity-based network[2]. MediaCups can sense movement, temperature and whether they stand or are lifted up. On board the augmented cup, more abstract context is computed from obtained sensor data, for example "cup is hot", "cup is carried around" and "cup is drunken from". Every two seconds cups broadcast state information via an infrared network into the LAN and potentially the Internet. Any application can listen for context information, and derive synthesized context, for example for awareness of co-located hot cups, which may serve as indicator for a meeting of people.

We have a small number of MediaCups in everyday use in our research group, gaining experience with respect to usability and utility but also with respect to context-awareness, for example:

- The separation of context acquisition and context consumption is valuable: development of applications is simplified, and acquired context can be used by multiple applications independently. This relates to findings from building a context toolkit reported in [3].
- In our system, synthesis of context information is responsibility of applications but we found that many applications have the same requirements for synthesis, for example to resolve co-location of artifacts.
- Applications often only need a subset of available context information, and we found that selection was most often based on evaluation of the location attribute of MediaCups rather than their ID.

TOWARDS AN ARCHITECTURE FOR PROVISION, SYNTHESIS AND USE OF CONTEXT

Based on our experience from the described projects we envision an architecture for context-awareness that takes further the separation of concerns (acquisition, synthesis and use of context), and that provides support for selection of available context:

- The architecture is centered on a context component that serves as mediator between context providers and context consumers.
- The context component keeps context information as set of so-called facts. Facts represent information obtained from logical and physical sensors, and provided by any kind of context provider, connected to the current time and the location.
- All facts have location and time as primary selection criteria: Fact=(location, time, value, description). Applications can define temporal-spatial regions of interest based on these selection criteria but this does not exclude selection by value or description.

The architecture is based on a blackboard model with three distinct interfaces:

- Context providers can write facts onto the blackboard.
- Fact abstractors can read facts for synthesis of new ones that they add to the board.
- Applications can read facts. The application can select facts of interest based on attributes.

[2] At http://mediacup.teco.edu/ information on the hardware, software, architecture, and the applications can be found.

The blackboard can be implemented efficiently as a database table with indices on time and location. Access to providers, abstractors and consumer can for example be realized over HTTP to facilitate existing infrastructure.

ABOUT THE AUTHORS

Hans Gellersen leads the TecO research group, and teaches courses on distributed multimedia and on ubiquitous computing at the University of Karlsruhe. His main research interests are ubiquitous and situated computing, information appliances, and human-computer interaction. In 1999, he organized the first International Symposium on Handheld and Ubiquitous Computing (HUC99), held in Karlsruhe.

Michael Beigl is currently completing his PhD studies at University of Karlsruhe with a dissertation on location models for communication in ubiquitous computing environments. His research interest in ubiquitous computing includes infrastructures for location- and context-awareness, privacy concerns in context-awareness, and human-computer interaction. At TecO, he leads the MediaCup project.

Albrecht Schmidt is a final year PhD student at University of Karlsruhe with research focus on situated interaction and technologies for context-awareness. At TecO, he is responsible for the European project TEA and other collaborative research efforts on context-awareness. He is organizer of the CHI'2000 workshop Situated Interaction in Ubiquitous Computing.

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