Alois Ferscha, Marc Langheinrich, Albrecht Schmidt
(Editors)

Current PhD Research in Pervasive Computing

First Int. Doctoral Colloquium on Pervasive Computing, Linz 2006

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Media Informatics Group

Preface

Introduction

Pervasive and ubiquitous computing is still a very young research field with many facets. PhD students and supervisors alike still ask the question what is excellent research in this area? The field is interdisciplinary by nature and hence the approaches taken to evaluated research are manifold. The applicability of traditional methods and tools is often questioned and new approaches are suggested.

With the Ubicomp and Pervasive Conference Series a premier forum for research in this area exists, that has, through its review process and program committee decision, shaped the way the community perceives quality research. Even though this provides common ground, there is still an ongoing process questioning how to conduct and present quality research.

With this doctoral colloquium we hope to contribute to this discussion and reflect on the way we do research. 20 PhD students from Darmstadt, Linz, München, and Zürich will present their research agenda and their preliminary results. The meeting, held at the University of Linz will provide a critical and constructive review of the ongoing PhD projects.

Alois Ferscha, Friedemann Mattern, Albrecht Schmidt

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Wednesday, March 22nd 2006

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Thursday, March 23nd 2006

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*Talks are 10 minutes each plus 5 minutes for Q&A

Session 1: Context Awareness, Activity Recognition and Sensors

Context Awareness in Mobile Computing

Andreas Zinnen

Technical University Darmstadt
TUD - FB 20
Multimodal Interactive Systems
Hochschulstraße 10
D-64289 Darmstadt
Germany

++49 6151 16 6227
zinnen@mis.tu-darmstadt.de

PhD-Supervision: **Prof. Dr. Bernt Schiele**

Doctoral Seminar, Linz, 2006

Abstract
Emerging applications in the field of mobile, wearable or ubiquitous computing try to include more of the user's context in order to better adapt the user interface (UI) to the user. Ideally, the computer would proactively act on the user's behalf. Within my PhD, I would like to identify which kind of context information is interesting within the scope of UIs and how this information can be used to customize the interaction between users and the system. Beyond context awareness, wearable devices require alternative input devices, e.g. sensor based gesture control. To support various types of devices, gestures ideally should be customizable, easy and quick to train.

Keywords
Context awareness, alternative human-computer interaction, gesture recognition

Problem Statement and Research Question
Gesturing is a natural form of communication. In many situations, users of a computer system cannot use a common mouse or a keyboard. Appliance of wearable computing in mobile settings requires alternative human computer interaction since computing and communication devices become smaller, lighter and more powerful. Speech recognition is not adequate in

many scenarios, e.g. doctors in health care [6] or noisy environments.

Alternatively, gesture recognition has been studied in various ways using a cap-mounted camera [5] or a glove-based system [3] to recognize sign languages. Acceleration based gesture interfaces are quite recent. In [4], the authors enable fast and effortless customisation in accelerometer based gesture interaction using discrete Hidden Markov Models. Most of the published papers about gesture recognition consider the recognition accuracy of a set of different gestures. I will extend this approach by investigating the gestures which are occurring in daily life to find distinguishable gestures for a Human Computer Interface. Ideally, those gestures should be easy and quick to train for everybody. Furthermore, the identified restricted set of gestures needs to be socially accepted to be used in daily life or work environments. Analyzing the non- and wrong-detection rate of the found gestures within daily life will be the most challenging part of the research. This set of gestures hopefully will offer a way to use gesture interaction without explicitly activating and deactivating the recognition system.

In a next step, I am interested in context information within the scope of UIs and how this information can be used to adapt the interaction between users and the system. Similar to the methodology proposed in [1], I aim to focus on applications that benefit from context-aware services. A central question in this area is the dynamic usage of context information within the software development process.

Approach and Methodology

As a prerequisite for acquisition of long term recording data of social gestures, a mobile sensor platform shall be set up. The goal is to have a mobile and stable recording platform, able to record 12+ h of sensor data in daily life without the need of a bulky backpack. In a next step, Hidden Markov Models will be used to train gesture recognition. The choice of features is crucial to obtain an acceptable non- and false detection rate of the chosen gestures.

Using this platform, we will gain the necessary data to evaluate the extracted set of gestures in an experimental way. The evaluation of their acceptance and directness will be analyzed in user studies with both students and doctors in the WearIT@Work project [6].

Finally, the research on concepts and methods for utilizing context information will be part of CESORA, a project between TUD and SAP. The design and prototyping of a context engine and the development of example applications based on business processes will consider and compare existing approaches [2].

Related Work

The authors of the paper “Context-awareness in wearable and ubiquitous computing” [1] present a research agenda on context-aware computing. They introduce mechanisms and architectures to support context-awareness and justify their effectiveness through case studies on applications that benefit from context-aware services. Context-aware computing is defined as "any attempt to use knowledge of a user's physical, social, informational and even emotional state as input to adapt the behaviour of one or more computational services".

“A Wearable Computer Based American Sign Language Recognizer” [5] describes a research effort to make a wearable computer that can recognize American Sign Language using a cap mounted camera for input. The language is interpreted using Hidden Markov Models and includes a set of forty words divided into the categories pronoun, verb, noun and adjective. The authors have achieved low error rates on both the training and an independent test set.

Anind K. Dey presents a context toolkit [2] providing important abstractions and support for the field of context-aware computing. The toolkit integrates input from several distributed computers. An additional layer transforms the context data to a form required by the context-aware applications. Context information is provided to multiple context-aware applications in the framework. The toolkit consists of three main abstractions – the widgets, aggregators and interpreters. Applications accessing the toolkit don’t need to know whether these context components are being executed remotely or locally.

Preliminary Results

N/A

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Multi-Sensor Context Awareness for Mobile Devices

Ulrich Steinhoff
Technical University Darmstadt
Hochschulstr. 10
64289 Darmstadt

+49 6151 16 5420
last name @mis.tu-darmstadt.de

PhD-Supervision: **Prof. Dr. Bernt Schiele**

Doctoral Seminar, Linz, 2006

Abstract

Within the many different kind of context possible and useful, especially the location tells many things about the user's overall situation. In turn, the knowledge about the user's context from other sources could also help to narrow down the possible location of the user if only an imprecise location is available.
GPS as the most popular system for location estimation fails inside buildings, where people spent most of their time. For a more general, reliable solution additional the augmentation with other positioning sensing techniques is needed. Possible approaches are inertial sensors, also useful for activity recognition, and widely available radio beacons like GSM and WiFi.

Keywords

Multi-modal context awareness, positioning, pedestrian navigation, sensor fusion

Problem Statement and Research Question

Motivated by the goals of the MOBVIS[1] project, I would like to investigate multimodal context acquisition, especially in terms of

- users context, focusing on
  - reliable positioning
  - user orientation and body posture
  - user activity

-semantic location using intelligent maps)
- Task context
- Digital context (connectivity)
- Context of environment (people around)

Main focus is a continuous space of visitor scenarios, ranging from a first time visitor with main interest in navigation to a permanent visitor with focus on capture&access.

Connected research interests are the possibilities for pedestrian navigation by multi-sensor fusion, including inertial sensors, WiFi, GSM and GPS, and enhancement of imprecise results by context knowledge about the users context and map information.

Approach and Methodology

Much of the research is of experimental nature. The first steps will be the building of miniaturized, reliable positioning platform for long term recordings, exploring the possibilities of step recognition/step length estimation with body-worn sensors as well as evaluation existing positioning techniques, e.g. dead reckoning modules, WiFi/GSM positioning (Placelab) and GPS availability. A possible direction of further research is not quite settled yet, but could be in the use of fewer and simpler sensors, compensated by the use of context information.

Related Work

In the field of pedestrian positioning by GPS combined with dead reckoning is done a lot of work, to emphasize is the early work of Judd [2] and the work of Ladetto [3], which yielded in commercial products. These approaches use sensors near the body's center of gravity and indirect step length estimation.
Strapdown integration of shoe mounted inertial sensors is presented by Foxlin [4]. An interesting different approach is presented by Eric Foxlin with.
In Fang et al. [5] the implementation of dead reckoning with networked sensors and a survey on pedestrian navigation is presented.

The authors of “Place Lab: Device Positioning Using Radio Bacons In The Wild” [6] present a open source system for positioning based on fixed radio beacons, such as WiFi-Accesspoints and GSM base stations. This system focuses more on an inexpensive, pervasive positioning solution than on precision.

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Acquiring Models of Everyday Activities for Robotic Control

Radu Bogdan Rusu
Intelligent Autonomous Systems
Computer Science Department IX
Technische Universität München
Boltzmannstr. 3
85748, Garching, Munich
+49 (89) 289-17780
rusu@cs.tum.edu
http://www9.cs.tum.edu/people/rusu

PhD-Supervision: **Prof. Michael Beetz, PhD**

Doctoral Seminar, Linz, 2006

Abstract
Intelligent sensor equipped environments can be of much greater help if they are capable of recognizing the actions and activities of their users, and inferring their intentions. An intelligent kitchen that recognizes what a person is looking for can highlight the target object. An oven noticing that the cook is on the phone can reduce the heating temperature, in order to avoid the meal getting burnt. In my dissertation research, I investigate the representation of models of everyday activities and study how such models can be learned from sensory data.

Keywords
Context-aware computing, intentional activity recognition, probabilistic activity models, sensor data fusion, artificial intelligence, cognitive robotic systems

Problem Statement and Research Question
Understanding human activities and characterizing them into expressive and detailed activity models is one of they key issues of today's current pervasive computing systems. If such a system could recognize and understand automatically its user's behavior, it could interact in a more efficient and friendly manner. Unfortunately, the current model construction techniques are based on supervised learning and require specifications from their human counterparts, such as

labeling the acquired sensor data. Our vision is to build technical cognitive systems that create and use models in a straightforward manner, by combining already existing online information with the system's context history.

Recent advances in the development of pervasive computing with an emphasis on wireless sensor networks, enable us to gather rich datasets of sensor streams. Understanding these data streams up to the level of inferring informative and detailed models of human activity from them is a challenging task.

Modern industrial robots are capable of performing very accurate and fast motions and manipulations. Their control programs are very concise and repetitive, but they can never be used for activities such as setting up the breakfast for a person, since they cannot deal with the uncertainties and probabilities associated with daily complex human activities.

The main motivation of our research is to build cognitive systems that can recognize and interpret accurately intentional activities of daily living, thus understanding and learning how to provide their users with a better overall experience.

By being able for instance to determine what activity a person is currently performing, and more importantly, how is (s)he performing that activity, we can build statistical representations of those daily activity experiences.

Our research focus concentrates on obtaining detailed models of daily activities and using them in both better understanding human actions and creating intelligent robotic household assistants. Before reaching our goal, we believe that we will encounter on the way, a series of questions that should be answered:

- What is the most appropriate way to represent these probabilistic models?
- How accurate can the models be, and how do we define a good model?
- Once built, how can the model be used by the cognitive system?
- What types of sensor streams and how much context history does a system need in order to build rich models?

A possible scenario could be the following one: after having learned for some time models of basic activities by observing the actions of people in a context-aware kitchen, the system starts its normal operation. A person selects a recipe from the World Wide Web, on an embedded touchscreen computer, and starts cooking. The system supports its user by highlighting where the tools are, what is the status of the ingredients, where should the actions be performed, etc.

The motivation of looking at complex everyday activities is that they do not require repetitive, constant actions such as the industrial ones, their execution is probabilistic and interleaved, they deal with a lot of uncertainties and need detailed action parametrization.

Approach and Methodology

So far, research in this field has been restricted on either building models of activities for ADLs ([1], [3], [8]) from RFID sensor data, or learning and classifying a predefined set of isolated activities, mostly from accelerometer sensor data. Very few, if none, have combined the two, or thought about the possibility of combining that information with already unsupervised learned models that a context-aware environment can give.

Also, in the context of building motion blueprints (described as movement primitives in [4],[5],[6] and [9]), the research was mostly focused on proving that a complex motion can be decomposed into a set of predefined, handcrafted, behavioral primitives, from either video data ([2]) or other types of complex motion capture systems. These data streams were rather hard to acquire and quite cumbersome to wear or act in front of, for the respective subjects.

We start building on these previously published results, but we envision technical cognitive systems that can record, analyze, interpret, and build models of human activities in an unsupervised straightforward fashion. These models will be later on used to build motion blueprints as a starting point for the developmental learning process of household robotic assistants, as well as for plan-based controllers.

During the last few months, we managed to create an excellent software infrastructure, building on top of the internationally renowned Player/Stage platform[10] (of which we are active developers), as well as on other opensource projects such as TinyOS[1]. This infrastructure is used both for sensor network deployment and data acquisition and serves as a bridge for data interpretation using machine learning algorithms projects such as Weka[2]. We conduct simulation experiments of household robotic assistants operated by plan-based controllers, as well as motion blueprints generation, clusterization and usage on our Powercube 6-DOF manipulators.

By analyzing the combined sensor data streams from a cognitive robotic perspective, we hope to be able to later on, build complex arm movements, for our B21 mobile robots, by sequentially combining and interpolating simple motion blueprints.

This work is including research topics from several different areas of science such as: artificial intelligence and learning, common sense reasoning, wireless sensor networks and robotics.

As an example scenario for validating and evaluating our research work, we are currently building a distributed sensor enabled environment (AwareKitchen) in our labs. We are making use of technologies such as B21 mobile robots equipped with Powercube 6-DOF manipulators, small embedded devices such as Gumstix that act as distributed sensor fusion nodes, wireless sensor networks (Motes, Particles), RFID tagged objects and readers, video and IR thermal cameras, as well as other types of sensors (for example, we are working together with people from the

[1] *http://www.tinyos.net*
[2] *http://www.cs.waikato.ac.nz/ml/weka/*

Ludwig-Maximilians University of Munich, in developing new capacity sensors that could be used to detect human motion).

Related Work

While some publications already covered areas of research such as inferring models of activities from sensor data, they mostly referred to the aspects of classifying an activity rather than reasoning about fine-grained details on how the activity was performed. In our research, we would like to take this one step further, since we believe that only very detailed models of human activities can be used in tasks such as building activity blueprints for a robotic household assistant.

Patterson, Fox et al.[1] present several results related to achieving fine-grained activity recognition for context-aware computing applications, but only from RFID data. They show the advantages of adding additional complexity to their previous models ([3], [8]) and conclude with a probabilistic model that can gracefully generalize classes of activities from object instances. While their work has a big impact on recognition and interpretation of RFID data, it does not say however, how is a certain activity performed, in terms of motion and environmental details.

Lee and Kim[2] developed a method for automatic gesture recognition from video data using Hidden Markov Models. They achieved good recognition rates of over 93.14% by introducing the concept of a threshold model (a complex garbage model or filler model) that calculates the likelihood threshold of an input pattern and provides a confirmation mechanism for the provisionally matched gesture patterns. They do not however, research if the same recognition rates can be achieved by using other types of sensor data, such as acceleration (for example), since optimal coverage for building such a model would be difficult to achieve and constrained by using just video data.

Perkowitz et al.[3] describe their experience on using the already existing knowledge from recipe web sites such as ehow.com and combining it with RFID sensor data to recognize more activities than a standard activity recognition system, which can only learn a tiny fraction of the thousands of human activities that are potentially useful to detect. They built an inference engine who accepts models from a mining engine and RFID sensor data as inputs and tries to provide activities with likelihoods as an output. The results are promising, but the resulted system does not make use of the entire knowledge available in a "recipe", thus the models only contain information about the objects involved in an activity and nothing about their properties, states, how are they manipulated, etc. We believe that by combining information from several recipe web sites and building more complex ontology models in knowledge bases such as Cyc, which already have strong commonsense reasoning engines, we will have a deeper understanding of how a certain activity is performed. The next step will be to create plan-based robot controllers that can be used by household robotic assistants to perform daily chores and complex tasks.

Jenkins and Mataric[4] address the problem of creating perceptual-motor primitives for a humanoid robot, from human motion capture data. The data is gathered from a Vicon optical motion capture system, which provides the trajectories of the markers in 3D, and the results are demonstrated in a dynamical humanoid simulator (Adonis). The motion primitives are however, manually crafted, and the motion capture system provides a cumbersome way of acquiring sensor data. We believe that multiple sensor streams, and combination of sensors such as RFID, accelerometers and even small laser units can provide an easier way of acquiring detailed datasets, in a non-intrusive manner. Furthermore, we are evaluating the possibility of building motion blueprints in an unsupervised manner by reasoning about previously acquired knowledge and combining it with the system's incoming fluent sensor streams.

The results presented in the above publications show the necessity of deeper research in the field. There are still plenty gaps to fill, and problems to solve, as we envision robotic assistants and context-aware environments that can automatically learn and build models of human activities, and then use them for interacting in a more efficient and friendly manner with their users.

Preliminary Results

Our efforts are concentrated right now on building the software infrastructure of a such cognitive system. We are currently developing and contributing with a lot of code and experience to the international cognitive robotics community.

The work is currently split into three major components:

- building complex, cognitive models of human activities in the ResearchCyc knowledge database by mining the world wide web, and using them together with sensor data streams by our inference reasoning engine for recognition and characterization of intentional activities;

- analyzing and interpreting streams of sensor data for building motion blueprints automatically, and using them for our B21 robotic assistants as a starting point in the developmental learning process;

- estimate the current activities and their states and provide a reliable source of information through multiple *sensor fusion nodes* in a context-aware environment for generating plan-based controllers for household robotic assistants.

Preliminary results have shown that we can build and cluster object usage in an intentional activity, by mining web sites such as ehow.com and extracting the appropriate instructions for that activity. After processing the information though several filters (such as Wordnet), we managed to create detailed representations of what objects are used and in what way in a certain daily activity.

We are experimenting with fusion of sensor data streams through the usage of wireless sensor networks and Player/Stage[10], for generating motion blueprints which can be used as a starting point in building and learning complex robotic arm movements. Our tests are being conducted on Powercube 6-DOF arms, mounted on a B21 mobile robot.

In the context of plan-based controllers, by modeling activities from sensor data, and fusing that with the existing knowledge about a certain activity, we can create better plans. Detailed recognition of the objects involved in an activity can lead to better image tracker routines which in turn, support a higher accuracy of the plan's execution routines.

Conclusions and Future Steps

To validate the results of our work, we are establishing application scenarios where this type of cognitive systems could prove to be useful. The initial testbed will be our AwareKitchen, a distributed sensing environment which we are currently building.

We will also investigate how we can transfer methods for learning action models that we have developed in the context of automatic football game analysis to this domain ([11]).

Another aspect of future applications of action models of this type, are action-aware control mechanisms for robots. We have proposed methods for the acquisition and usage of action models for the improved control of robot soccer and service robots ([12], [13]).

We are looking forward for cooperating and participating in projects together with other research groups.

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Emotional Interaction (Human-Machine Influence)

Dipl.-Ing. Andreas Riener
Johannes Kepler University Linz
Institute for Pervasive Computing
Altenberger Straße 69
A-4040 Linz/Donau
+43/732/2468-8527
riener@pervasive.jku.at
http://www.pervasive.jku.at

PhD-Supervision: **Univ-Prof. Dr. Alois Ferscha**

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Abstract
The extensive propagation and usage of computers, cell phones, PDAs, MP3-players, etc. in our everydays-life (and particulary in almost any situation) causes the opportunity for interacting with computers away from the desktop in an increasing amount [4] - with the consequence, that the role of the user and his interactions in this environment become more and more variable.

In my PhD thesis i will propose a software framework with corresponding hardware to support the interaction between human and computer in an implicit (non invasive) way by measuring and processing biological signals (the intention is to detect emotional states and react on it) with the goal of controlling computing devices by this.

Keywords
Emotional Computing, Similarity Analysis, Emotional Interaction, Human-Centered Computing, Aesthetics and Computation.

Problem Statement and Research Question
Computers need to be able to sense and interpret emotions in order to respond intelligently to (complex) human interactions.

A big challenge is to unravel the "functionality" of human's emotion and to build devices that detect and reflect emotional states.

The terms affect, mood and emotion are fundamental aspects of human beeings and it is well-known that this "parameter of feelings" can influence cognition, perception, social judgement, behaviour, etc. [1].

Affect and emotion are often used as commonly understood neutral terms to represent mood, feelings, etc. in general – thus i want handle this in my work in the same way.

Approach and Methodology
My approach for measuring, classification and processing of signals with a corresponding feedback to the "real-life" system is to split the process into multiple, independent stages as accounted in the next subsection.

Multi-level emotion recognition
The action of emotion processing can be divided into several autonomous stages as depicted in the figure below.

1) Biophysical sensing
Emotions in people consist of a constellation of regulatory and biasing mechanisms. Emotions can affect the voice rate, the mode of sitting, standing or walking, the type of gesturing, the kind of communicate which one another, etc.

Until now, the most explored fields of human-machine interaction are automatic facial expression and vocal inflection recognition [2].

On biochemical and pysiological sensors are e. g. conceivable: electrocardiogram (ECG), bloodgas (blood oxygen)-sensor, skin-humidity sensor, skin-conductance sensor, blood sugar sensor, etc.

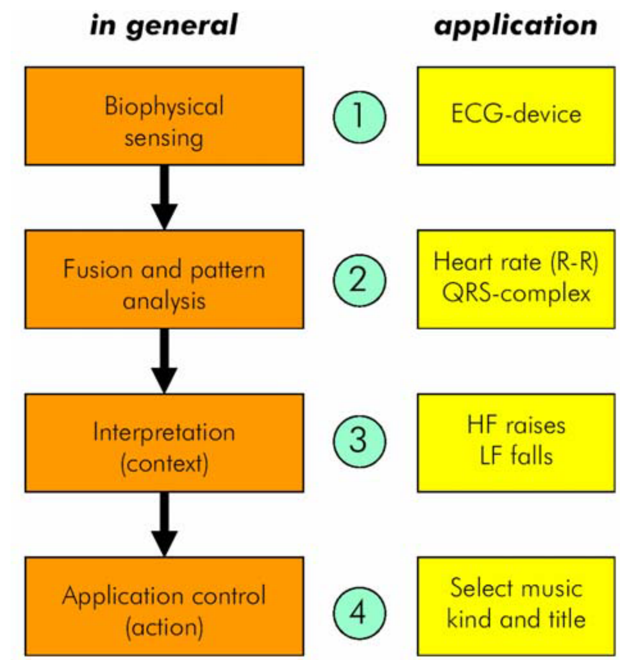

Fig. 1: Multi-level emotion recognition

2) Fusion and pattern analysis
In this stage the main functionality of the framework and the innovation is resided. (Multi) sensor values has to be evaluated, then classified based on dynamic or discriminative models and finally compared to a) other sensor values or b) data sets from a database to identify matching (emotional) patterns.

3) Interpretation of emotional states
For context constrained interpretation still frequently

humans are necessary, but in the next step this should be independent performed from a computer system, eg. by aquiring cognitive informations from a knowledge base, etc.

4) Application control
With the result(s) from the previous stages the corresponding actions can be performed, give a direct user-feedback based on the measured sensor-values.

According to the person's interaction-interest and manner the systems state can be dynamic in a high degree (user action → change in systems state → user feedback → modified user action → …).

Related Work

Lots of work has been done in the last years, i think present existing approaches of emotion recognition could be classified in the following way:

1) **Emotional state recognition based on sitting, standing, walking and hand gestures**

2) **Face/Eye tracking, Speech/Voice recognition**

3) **Stress metrics (skin temperature, conductance and humidity, etc.)**

4) **Heart rate, Electrocardiogram**

5) **Multi sensor fusion systems**
Measuring of lots of sensor values, classify and/or identify "isles of mood states" etc.

Preliminary Results

1) Impact of music on emotional states
In [3] as well as in figure 1 and 2 the impact of music on emotional states is shown.

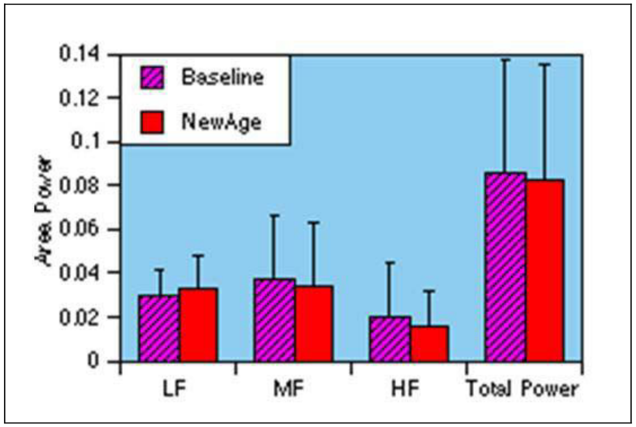

Fig. 2: Impact of Music to Heart rate variability (1)

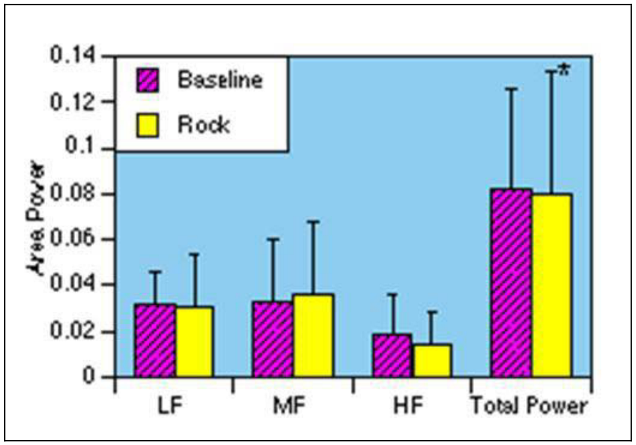

Fig. 3: Impact of Music to Heart rate variability (2)

The result of this confirmed series of tests should be extended, e.g by performing an evaluation how different titles and/or kinds of music (classic, rock, heavy metal, etc.) affects the biological state of a human (heart frequency, heart rate variability, skin humidity, running performance, and so on).

2) Empiric methods in emotional computing

Working in the field of emotional computing is not limited to measuring, recording, classifying and evaluating of biological signals (e.g. the ecg-signal as shown in the figure below); until now i still have recognized that is is also necessary to do research work in the field of empiric methods to get a fundamental base for the PhD thesis (commonly electrical biosignals are measured – e.g. the heart frequency, the heart rate variability HRV, the oxygen content in the blood, the skin resistance, etc. -, processed by a computing device; finally the results are depicted as visual or audio-visual output. But this approach still needs the classification and/or interpretation of the parameters/attributes by a human!).

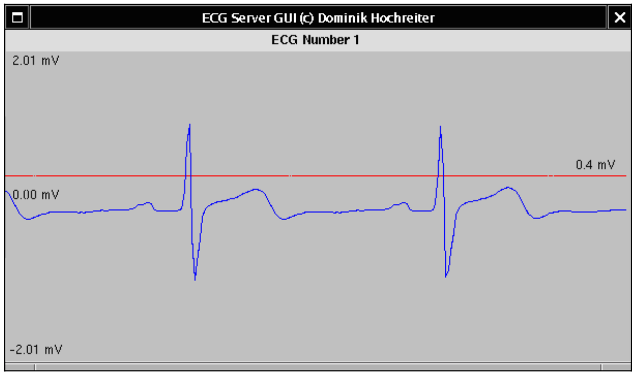

Fig. 4: ECG signal recorded from a "HeartMan" via bluetooth

To present the technical solution alone is unsufficient, even more it is absolut required to place the PhD-thesis on an empirical framework (music as modification parameter for emotional, mood states, as attribute for changing the heart rate variability, etc.).

3) Sensors and skills

Another important work package is a survey about (robust) "biophysical sensors" and their abilities. As the result a table consisting the various sensors with their price, degrees of freedom, accuracy, interfaces, power consumption, etc. should be presented.

Conclusions and Future Steps

Today i am quite at the beginning of my PhD, until now i have concentrated my work in recording and processing electrocardiogram (ECG) signals and performing similarity analysis on multiple ecg-streams (for details see figure 5 or the project "HeartBeat", an installation in the course of the ars electronica festival 2005).

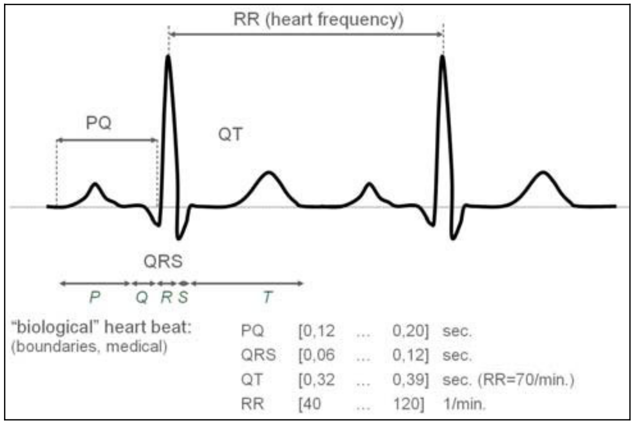

Fig. 5: Ecg features used for similarity analysis in "HeartBeat"

The next steps will be an empiric evaluation of the influence of music to emotional states (as discussed in [3]), the implementing of a similarity library for supporting pattern recognition and similarity analysis in biosignals.

A joint research project, titled "HeartMusic", which should be started in the next weeks, deals with the thematic field "feedback of a humans biological state to the playlist of a music playing device".

I im interested in cooperations as result of the international doctoral seminar, especially for discussing the step of processing and/or interpretation of biosignals, which are measured as (ordinary) electrial units.

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Session 2: Wireless Sensor Networks

Configuration of Wireless Sensor Networks

Christian Frank
ETH Zurich, IFW D41.2
8092 Zurich, Switzerland
+41 44 63 24426
chfrank@inf.ethz.ch
www.inf.ethz.ch/~chfrank

PhD-Supervision: **Friedemann Mattern**

Doctoral Seminar, Linz, 2006

Abstract

Wireless ad hoc networks of sensor nodes are envisioned to be deployed in the physical environment to monitor a wide variety of real-world phenomena. My PhD project is concerned with the configuration of wireless sensor networks and with generic high-level programming abstractions for specifying configuration problems.

Keywords

Wireless sensor networks, self-configuration, programming abstractions, facility location

Problem Statement and Research Question

Configuration of wireless sensor networks is an essential element for the efficient operation of these networks, as it enables, for example, more efficient routing and data gathering approaches.

Further, *automatic* configuration is required as manual configuration of individual nodes is not possible due to the envisioned network size. *Distributed* configuration is required as centralized offline configuration is often infeasible due to the prohibitively high effort required to collect in-situ node parameters (such as node position or network neighbours) at the sink.

Last but not least, *generic* high-level abstractions are important as these make life easier for application-domain experts (vulcanologists and the like) which are envisioned users of wireless sensor networks and currently struggle with low-level programming of the available prototype systems.

Preliminary Results

So far, we have studied a generic programming abstraction that allows for rapid prototyping of sensor-network configurations – such as clustering – using concise declarative programs [1]. Specifically, we have looked at the efficiency of a distributed implementation [2] and at the properties of an exact solution of the specified configuration problems through a generic translation of specified configuration problems into integer linear programs (ILPs) [3].

Conclusions and Future Steps

The current distributed approach [2] did not focus on optimality of the obtained configurations, but on ease-of-use (specifically that the desired configuration could be described in only a few lines of code) and on an efficient implementation of the distributed algorithms. In the future, I plan to investigate how similar configuration problems can be supported by a distributed approximation of the *facility location problem*, which has previously been used in operations research to place distribution centres such that they (optimally) serve customers, e.g., in a street network. The envisioned algorithm, being a generalization of the *minimum dominating set problem* commonly approximated in clustering algorithms, can be parameterized more flexibly and be applied to a larger class of configuration problems – compared to existing algorithms (e.g., for clustering or data aggregation) that have been studied in related work so far.

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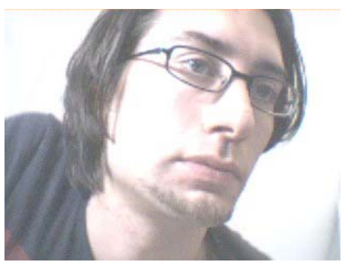
Deployment Support for Wireless Sensor Networks

Matthias Ringwald
ETH Zurich
Clausiusstrasse 59
+41 44 6326136
mringwal@inf.ethz.ch
http://people.inf.ethz.ch/mringwal

PhD-Supervision: **Friedemann Mattern**



Doctoral Seminar, Linz, 2006

Abstract

Wireless Sensor Networks (WSNs) - networks of small resource-constrained devices that are able to sense their environment and communicate with each other - have received a growing interest by academia and industry in the past years. However, the number of actually deployed sensor networks is rather small and those are in the order of tens of nodes instead of thousands. The focus of this thesis lies on the analysis of real-world WSN deployment issues and on the provision of concepts and tools to facilitate the implementation of WSN applications, to monitor deployed networks and to allow for efficient identification and solving of WSN problems.

Keywords

Wireless sensor networks, deployment, monitoring, maintenance, debugging, testing, distributed systems.

Problem Statement and Research Question

So far, deploying a WSN is considered an *art,* performed by a WSN system programmer and not by an application domain expert. This thesis aims at bridging this gap by identifying main real-world deployment issues and providing concepts and tools to cope with these, based on the availability of an additional deployment-support network (DSN)[1], which is temporarily installed next to the main WSN. More specifically, this thesis will focus on the media access and routing layers, as these are required for most of the WSN applications and are a common cause for failures. We will address the questions of what kind of problems can be identified and solved by eavesdropping on exchanged radio messages and how well distributed debugging techniques, such as deterministic replay and unit testing, can be applied in WSNs.

Approach and Methodology

Researchers deploying wireless sensor networks in real applications face various problems not seen in simulation or lab tests. The thesis will start by surveying existing WSN deployments and their reported issues. As sensor networks are optimized to fulfill their task with a minimal energy-consumption, it is hard to collect enough information to understand and solve such problems. Gathering exhaustive information from the sensor network for debugging purposes would require changes to the distributed application itself and might lead to additional bugs. Therefore, in this thesis, the usefulness of an additional deployment-support network will be evaluated. This DSN can be used in two ways: First, in an unobtrusive way to observe exchanged radio messages, and second, as a way to directly control WSN nodes from a central node to allow for distributed debugging and to introduce distributed unit tests. As an example application, the newly developed BitLMAC media access protocol based on BitMAC[2] will be implemented using the proposed DSN approaches.

Related Work

Existing works in the area of deployment support for WSNs follow different approaches. Real-world deployments are conducted to gain experience. Indoor testbeds consisting of wired sensor nodes, which provide power and a direct communication backchannel, are used to test applications before they are deployed on real sensor nodes outdoors. Two recent projects aim at providing insight into single sensor nodes such as the Nucleus network management system (NNMS)[3], or collecting additional statistics of the whole network to detect and identify failures like Sympathy[4]. Both approaches require to run additional program code on the sensor node and create additional network traffic. A deployment support network provides the benefits of a wired testbed to a deployed WSN. This thesis builds upon on the availability of a DSN, which will be used in the two proposed ways. Both the metrics described in the Sympathy paper as well as the data accessible by Nucleus can be used as a test case for the abilities of the DSN.

Future Steps

The next steps will be to further investigate papers on WSN deployments in more detail and to analyse conditions on which these problems could be solved with a DSN. Then, a tool to aid in development and debugging of the MAC layer will be built. As a real-world test, BitLMAC will be implemented using this tool.

Potential Collaboration

To gain a better insight into real-world problems, reports and feedback from groups deploying large WSN are highly appreciated. Also, it would be beneficiary to test and evaluate the developed tools in such settings.

As WSNs are a specific instance of distributed systems, expertise on available techniques for debugging and distributed (unit) testing and their applicability for WSN would be helpful.

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Collaborative Data Management for Wireless Sensor Networks

Silvia Santini
ETH Zurich
Clausiusstrasse 59, IFW D41.2
+41 44 632 4142
santinis@inf.ethz.ch
http://people.inf.ethz.ch/santinis/

PhD-Supervision: **Prof. Friedemann Mattern**

Doctoral Seminar, Linz, 2006

Abstract
Collaboration among individual nodes in wireless sensor networks can facilitate distributed, energy-efficient data collection, processing and transmission. My research concerns the design and testing of efficient, robust and scalable adaptive algorithms for collaborative data management in static and mobile wireless sensor networks.

Keywords
Wireless sensor networks, data management, adaptability, mobility

Problem Statement and Research Question

Providing fine-grained observations of real-world phenomena is a common requirement for many sensor network applications. However, continuously reporting accurate data represents a significant communication overhead (thus increased energy consumption) for sensor nodes. In order to preserve network resources it is thus necessary to limit the amount of data to be sent, while at the same time maintaining the accuracy of the delivered data to fulfill the given application requirements. The main focus of my research lies in designing and evaluating collaborative data collection, processing and transmission frameworks based on adaptive algorithms that minimize network resource usage (i.e., energy) while preserving data accuracy.

Approach and Methodology

A performance analysis of classical adaptive algorithms for data reduction in wireless sensor networks constitutes the starting point of this work. Improvements upon these algorithms are then needed to get rid of unreliable wireless communication and to enable resilience to changing network configuration. Finally, the role of node mobility for collaborative data management will be investigated as an opportunity for further optimization. The theoretical evaluation of the algorithms will be accompanied by various prototypes on real test-beds.

Related Work

Several different approaches for data management in wireless sensor networks have already been proposed. An interesting methodology and extensive experimental results are presented in [1], where data reduction is obtained through a prediction scheme based on classical Kalman filter theory. In [2] a global spatio-temporal probabilistic model for network-wide sensor data is derived from past observations and used to estimate the current response of the network to a given query. In both these approaches collaboration among nodes is limited to the classical client-server model. In [3] Howard et al. show how sensor nodes can share locally collected data and cooperate in order to reach autonomously an optimal network configuration. Even if thematically not directly connected to [1] and [2], this work offers interesting ideas on how to exploit node mobility to increase global network performances.

Potential Cooperation

This work would benefit from cooperation with researcher from the field of autonomous robotic systems and learning algorithms.

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Programming Abstractions for Large Scale Deployment of Wireless Sensor Networks

Jonas Wolf
ETH Zurich, IFW D47.2
Haldeneggsteig 4
CH-8092 Zurich
+41 44 63 20862
wolfj@inf.ethz.ch
http://www.inf.ethz.ch/~wolfj/

PhD-Supervision: **Friedemann Mattern**

Doctoral Seminar, Linz, 2006

Abstract
Wireless sensor networks have been an active area of research in the past years. This research has fostered the development of a multitude of different hardware and software platforms as well as several potential application scenarios. Unfortunately, a functional large-scale, non-academic deployment of a wireless sensor network is hitherto unknown. Currently, expert knowledge is required to implement even simple, functionally limited wireless sensor networks. We envision a programming application framework that simplifies deployment by abstracting from the low level implementation of individual nodes and focusing instead on the objectives of the entire network.

Keywords
wireless sensor networks, programming abstractions

Problem Statement and Research Question
At present, programming wireless sensor network devices is a very low-level task that requires intimate knowledge of the underlying hardware and software technologies. Furthermore, applications for wireless sensor networks are largely tailored to the particular target platform and can not be ported easily. In addition, the designer usually imposes functionality and capability statically at compile-time, which means that

each node fulfils one specific task throughout its lifetime, and this task needs to be determined in advance. As a result, deploying large wireless sensor networks is a time-consuming task that can not be executed by the typical envisioned user. These limitations currently inhibit wireless sensor networks as an enabling technology.

Wireless sensor nodes should be dynamic entities with the ability to adapt to the changing environment, in order to serve a common goal. Hence, we would like to suggest a shift of paradigm in programming wireless sensor networks. Instead of focusing on the implementation of individual nodes and their respective responsibilities, we would like to program the network as a whole by specifying more abstract goals. This requires developing appropriate tools that can transform a higher level sensor network specification into low level code for deployment on individual nodes. Together, the nodes then perform the specific task at hand, including coordinating and changing responsibilities automatically when necessary. Ideally, the user should not need to worry about the tasks of individual nodes (unless he has a specific interest in doing so) because the network as a whole achieves the desired goal.

Approach and Methodology

We will first identify the exact requirements of a suitable programming application framework based on the desires and capabilities of our typical envisioned user, as well as typical sensor network application scenarios. Ongoing research in the areas of MAC protocols, energy efficient data acquisition, storage and retrieval, and dynamic ad-hoc networking will be scrutinised in order to assess suitability for inclusion into the framework. A programming application framework will be designed, prototyped and analysed.

Related Work

There are various research activities that address individual aspects of the problem described. TinyDB [1] is an implementation of a distributed database that runs on sensor nodes. TinyDB allows the user to formulate queries concerning the network as a whole, abstracting from individual nodes. Barr et al developed MagnetOS [2], a distributed Java virtual machine for sensor nodes. Applications are written as if they were executed on a single machine and the sensor network automatically partitions the resulting program into components that are migrated to the most suitable node for execution. SensorWare [3] and Agilla [5] are mobile agent based sensor network frameworks. SensorWare provides a higher level language to express distributed algorithms that abstracts from low-level details and provides resource sharing among nodes. In Agilla, the network can react to changing circumstances by migrating agents between nodes, and as with MagnetOS, code is written as for a single machine. Finally, DSWare [4] operates between the network and application layers of a sensor network and provides a database-like abstraction to applications. Lower-level characteristics such as unreliability of sensor or communication devices are hidden from the user.

Conclusions and Future Steps

Considering their huge potential in a large number of application scenarios, wireless sensor networks are not as widespread as they could be. Current research offers the vision that application experts are able to deploy wireless sensor networks in their field of expertise with little to no support from technology experts. In order to bridge this gap, a number of programming abstractions have evolved with the goal of making the technology more accessible. Nonetheless, work in this field is far from complete and provides plenty of further challenges.

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Session 3: Systems and Architectures

Design Guidelines and Design Patterns for Ubiquitous Computing

Matthias Kranz
Research Group Embedded Interaction
University of Munich
Amalienstrasse 17
80333 Munich
+49 89 2180 4656
matthias@hcilab.org
http://www.hcilab.org/matthias/

PhD-Supervision: **Albrecht Schmidt**

Doctoral Seminar, Linz, 2006

Abstract
Design patterns and guidelines greatly help to facilitate the software development process, e.g. in object-oriented software engineering. Little research so far has focused on applying these powerful methods to application development in ubiquitous and pervasive computing. As for many other methods, e.g. from traditional GUI design, not all patterns apply to the young research area of ubiquitous computing. Also, novel patterns like context-sensitive I/O emerge. My research focuses therefore on design guidelines and design patterns for ubiquitous computing.

Keywords
Ubiquitous Computing, System Architecture, Design Process, Design Patterns, Development Guidelines, Design Guidelines

Problem Statement and Research Question
The motivation for my research is to improve the development process and the overall system quality of systems and applications in the field of ubiquitous and pervasive computing. This will, hopefully, result in more deployed real-world installations, which, if these systems prove successful, will implicitly find their way into everyday homes. This opens new markets and business opportunities for commercial products of the

conducted and applied research in this young field in computer science.

‘A pattern is the abstraction from a concrete form which keeps recurring in specific non-arbitrary contexts’ [1]. Design patterns have proved to be a valuable help and tool for system developers, especially in object-oriented software engineering. Patterns provide solutions to recurring problems and enable the reuse of existing knowledge. This prevents engineers, developers and designer from reinventing the wheel all over again.

Ubiquitous and pervasive computing are relatively young research areas in computer science. Though, a lot of research on application potentials and demonstrators has been done recently, formal approaches have only been investigated with specific focuses so far, e.g. privacy or security. General research on software engineering issues like architectures, middleware and communication have not resulted into a commonly agreed on answer so far.

My research focus therefore concentrates on design guidelines and design patterns for ubiquitous and pervasive computing. This will especially include the following research questions:

- How can methods from software engineering be applied to ubiquitous computing?
- Which design guidelines and design patterns can be applied and which have to be modified?
- Which new design guidelines and design patterns emerge in the context of ubiquitous and pervasive computing? This will comprise the whole development cycle from an initial idea to the evaluation of the deployed system.
- Which design and development issues are crucial for a successful real-world deployment of a ubiquitous computing project? Clarifying on this question should help to produce more successfully deployed systems.

From other recent research it is known that methods e.g. for system evaluation do not apply because of the nature of ubiquitous computing applications like the distribution and number of interaction interfaces [5]. Novel design patterns like context-sensitive I/O are unknown in standard software engineering [2]. This is the result of the properties specific to ubiquitous computing systems as for example the huge number of involved devices and the different input and output modalities.

The goal of this research is to discover and validate existing and novel design guidelines and design patterns. The advantages of using formal software engineering methods throughout the complete development cycle of a ubiquitous computing project is expected to result in more and better applications that can break the barrier from a lab-only systems to successfully deployed real world systems which are more suited and tailored to the needs of all involved stakeholders.

Approach and Methodology

So far, no general analysis of presented architectures has been conducted to find similarities. Most presented middlewares and frameworks are rarely used in more than one project or by other research groups.

Initial research on design patterns has focused on commercial products, not on research projects [2]. Therefore, my research will start by an analysis of recent research projects to discover the key aspects for their success from a software engineering perspective.

During my research, several smaller and larger ubiquitous computing projects have been developed and deployed. This knowledge will be used as a basis for analysis and comparison against other research. My research in e.g. the larger projects on the Display Cube or on computer-augmented pieces of sports equipment will serve as a solid basis.

As of now, only little research has been done on software engineering issues related to design patterns and guidelines. Published work mostly focuses only on small aspects like privacy or evaluation [5].

By analyzing existing successful ubiquitous computing applications, I hope to be able to discover emerging patterns and key factors for their success. Incorporating this knowledge into my own research projects will enable me to validate and verify the found patterns and guidelines with first-hand knowledge. This will also include the participation in research projects primarily done by other research groups. This kind of external view on ongoing projects will help me to take the necessary step back from my own research and to gain a more objective view on my research.

Related Work

The initial publications on patterns and pre-patterns [2] present a large number of emerging pre-patterns for ubiquitous computing. The authors called their patterns pre-patterns because they are still emerging and are not in common use yet. By my research, I hope to be able to extend this work to develop a first catalogue of stable patterns and to verify their validity in my research projects. As the authors did not continue their work published in 2004, I will as a first step, update their pattern catalogue with current research projects employing their pre-patterns.

Banavar and Bernstein present a comprehensive scenario of how ubiquitous computing could interweave in our life [3]. By their scenario they identify a great number of application design and architectural challenges. This analysis is a good starting point for identifying necessary patterns for ubiquitous computing development.

Roman et. al. [6] describe their experiences gained from building a ubiquitous computing infrastructure over a three year period. In this environment, they build a great number of applications. From this, they identified six design patterns for ubiquitous computing that were required by all applications. These patterns were multi-device utilization, user-centrism, run-time adaptation, mobility, context-sensitivity and ubiquitous computing environment independence. Some of these patterns have already been identified in [2], like context-sensitive I/O.

The results of the related work revisited show the necessity for a deeper research in design patterns specifically suited towards ubiquitous and pervasive computing.

Preliminary Results

My initial publications on my Ph.D. research topic up to now were focused on smart object systems and the development of ubiquitous computing infrastructure by extending, modifying and hacking existing commercial off the shelf hardware. Results showed that these approaches are a successful way of speeding up and facilitating the development process itself and that the appliances that came out by applying this process are more usable.

Conclusions and Future Steps

Patterns in general are an appropriate means of reusing previously gained knowledge and facilitate the development process. Patterns research in ubiquitous computing is still in a very early stage. Continuing research in this direction promises to help application developers to faster built better applications in this research area.

The next steps of my research include an analysis of recent projects to identify and validate appropriate patterns. By analyzing existing design patterns and design guidelines e.g. for object-oriented software engineering, HCI and user interfaces, like the Mac OS X, I hope to develop the necessary expertise and familiarity for patterns in general. From this, I hope to be able to develop a hierarchical pattern language for ubiquitous computing.

To validate the results of this work, I will on the one hand employ the developed knowledge in own ubiquitous computing projects, and on the other hand participate in research projects conducted by other research groups. I especially look forward to contribute my knowledge to the intelligent environment research of Prof. Beetz of University of Technology, Munich.

A three months stay at a second institution as visiting researcher would enable me to again validate my research and finalize the to-be-developed patterns and guidelines for ubiquitous computing.

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Self-Description and -Management of Orientation-Aware Artefacts

Clemens Holzmann
Johannes Kepler University Linz
Altenberger Straße 69
+43 732 2468 1226
clemens.holzmann@jku.at
http://pervasive.jku.at

PhD-Supervision: **Alois Ferscha**

Doctoral Seminar, Linz, 2006

Abstract
The topic of this PhD thesis is the composition and aggregation of physical artefacts in a generic way, where the focus is on the utilization of spatial orientation for both context acquisition and interaction. It also involves the construction of real-world user interfaces from a collective of orientation-aware artefacts, as well as means for inferring context information from orientation at different levels of complexity. The basis is a software framework that implements life-cycles of such artefacts which are able to describe themselves to their environment. In addition, the framework can be extended with tools for visual composition and aggregation to ensembles of artefacts.

Keywords
Context awareness, interaction modalities, orientation sensing, self-description and -management, tangible user interfaces.

Problem Statement and Research Question
The focus of my research is on the utilization of **spatial orientation** of physical artefacts, which is valuable information for both context acquisition and interaction. In this respect, the research mainly contributes to two fields.

The first one is the field of **tangible user interfaces**, where the use of spatial orientation opens up novel interaction modalities. For example, simple and intuitive manipulations and gestures performed with one or more orientation-aware artefacts can be used for controlling the environment. In this respect, orientation information is useful for both selecting and controlling multiple devices as well as services in a natural way.

The second research field is **context computing**, namely the utilization of information about the situation of an entity. Low-level data from orientation sensors like information about the manipulation of an artefact or its static orientation, metrics like angular acceleration or all kinds of statistical numbers calculated from a time-series of orientation-values, and high-level information like activities and gestures inferred from both sensor data and metrics, provide a rich source of context information.

For both fields, the ability of artefacts to **describe themselves** to other artefacts and the environment, as well as their **self-management**, namely the management of their interactions and activities in a decentralized manner, are central issues. This is of value as the respective artefacts should coordinate themselves or provide suggestions to the user about how they can be used in combination, in order to unburden humans from configuring and managing these environments.

My **central research interests** are (1) to develop novel interaction modalities and to identify high-level context information based on spatial orientation, (2) to find simple and generic means for self-description and –management of artefacts with a focus on orientation information, and (3) to develop a flexible and extensible software framework which implements the life-cycles of self-describing artefacts on the one hand, and allows their composition to ensembles for interaction and context acquisition on the other hand.

Further aspects I intend to address in my research are **design guidelines** and **process models** for the development of interfaces with multiple self-describing physical artefacts.

Approach and Methodology

The research is both experimental and theoretical. The **theoretical** parts comprise the development of new interaction modalities and the identification of context information based on spatial orientation, the development of a generic self-description for artefacts as well as a framework that executes their life-cycles and provides means for composing them, and an analysis and comparison of approaches for self-management. On the other hand, the research is **experimental** with respect to implementing a software framework and evaluating it with application scenarios.

The **validation and evaluation** of the quality of my research is primarily based on reviews and feedback to related publications and presentations, respectively. I think that sharing ideas with an international group of experts is appropriate in the context of my work, as it is evaluated from many different viewpoints thereby. Moreover, a survey of recent literature and discussions with my supervisor as well as colleagues working on similar topics helps me keeping up to date and getting early feedback about my work.

Related Work

This section explains in short **important publications** that had a major impact on my research field. First, K. P. Fishkin proposes a definition of and taxonomy for **tangible user interfaces** in [2], along the dimensions embodiment and metaphor. An early related work of H. Ishii et.al. about TUIs can be found in [3]. Another relevant paper written by S. Greenberg et.al. introduces the concept of "phidgets" [4], which are to **physical user interfaces** basically what widgets are to GUIs. Additional work related to physical user interfaces can be found in [5], [6] and [9]. A comprehensive overview of **context computing** is given in the PhD thesis of A. Dey [7] and A. Schmidt [8].

Preliminary Results

In comparison with the related work mentioned above, I see the **contribution of my thesis** in the composition of ensembles from physical artefacts which **describe themselves** to others and have a **controllable life-cycle**, where both the life-cycle and the self-description depend on their current **context**. In this respect, the general focus is on the use of **spatial orientation**. The **composition of artefacts** as well as automatic code-generation and -deployment are planned to be supported by a graphical user interface, allowing a rapid development of real-world user interfaces.

The **preliminary ideas and results** are:

- Survey and taxonomy of orientation sensing systems (from a technological viewpoint) as well as concepts for using spatial orientation
- Interaction modalities using cubes (change services and their parameters by flipping and turning the cube, respectively) and knobs (connect to devices in close proximity and control them in continuous or discrete ways)
- Development of an architecture for gesture-based control with orientation-aware artefacts
- Interaction paradigm for orientation-based selection and control of multiple arbitrary devices as well as services (browse devices and services with rotary movements and select/deselect them with tilt movements)
- Architectural ideas for the lifecycle control of artefacts, their self-descriptions and composition to ensembles by visual means
- Five-phase design-process for building real-world interfaces

Conclusions and Future Steps

My **next steps** are planned to be as follows. First, I will develop an XML-based **self-description** for artefacts (with PML [1] as starting point), which also allows their linkage to ensembles as well as the embedding of in-line code. Related with the self-description of artefacts is the description of whole ensembles of artefacts (similar to graphical user interfaces, which can also be described with XML-based languages).

Second, I intend to implement a **plug-in framework** based on OSGi that supports the lifecycle control of self-describing artefacts for context acquisition or interaction. In this respect, an interesting issue is the investigation of context-dependent adaptation of life-cycles as well as the artefacts' self-descriptions. In addition, an Eclipse-Plugin for composing artefacts by visual means as well as automatic code generation and deployment is planned to be developed.

In parallel to the first two steps, I will think about **application domains** and develop **scenarios** for such self-describing and -managing artefacts that are aware of their spatial orientation. From my viewpoint, this is not only important with regard to building prototypes for evaluation purposes, but also for getting new ideas.

Further issues are the investigation of feedback mechanisms for controlling real-world interfaces with everyday objects as well as the systematic combination of orientation data with other contexts like identity and location.

I would like to **cooperate with others** in the discussion of novel interaction modalities, the investigation of application scenarios for self-describing and -managing artefacts, as well as the development of a software framework as outlined above.

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Smart-Object Services for Consumers

Christof Roduner
ETH Zürich
Clausiusstr. 59
+41 44 632 04 34
rodunerc@inf.ethz.ch
http://people.inf.ethz.ch/rodunerc/

PhD-Supervision: **Friedemann Mattern**

Doctoral Seminar, Linz, 2006

Abstract

Auto-id technology, i.e. technology to uniquely identify real world objects, has drawn considerable interest from researchers in the past few years. While most projects are directed towards improving enabling technologies, such as RFID, or applications in closed-loop corporate environments, such as supply chain management, this thesis's focus lies on the use of auto-id technology for providing services to end-users. More precisely, the infrastructure that is needed to easily augment consumer goods with information services will be investigated and, as a result, a set of core software components will be implemented to facilitate the creation and deployment of such services.

Keywords

smart objects, tagging, infrastructure, architecture, law and economics, consumers, EPC Network

Problem Statement and Research Question

If we assume that it becomes common practice to bind information services to consumer products, it is obvious that there will be a need for a shared infrastructure to facilitate the creation of such services and avoid duplicate effort. This thesis thus aims at identifying infrastructure gaps and providing software components to fill them. Moreover, many of the scenarios on smart-object services have the potential to influence the value chains of suppliers, have an impact on market structures, and give rise to controversial discussions among stakeholders. This thesis will thus also be concerned with the economic and social environment of future smart-object services.

Approach and Methodology

This thesis will start by describing and classifying a number of scenarios on how the value of physical objects can be enhanced by the offering of information services attached to them. These scenarios will be used to identify components that should be readily available in order to allow manufacturers to easily augment their products with information services. A software architecture will be proposed, implemented and validated by prototyping some scenarios. These activities will be accompanied by economic, social, and legal considerations, as it is a goal of this thesis to obtain a holistic view on application scenarios.

Related Work

EPCglobal [1] is currently the predominant standardization effort in the domain of software architectures for RFID systems and item-level tagging technologies in general. The architecture developed in this thesis should consider the relevant concepts proposed by the industry and, as far as possible, build upon them. Lessig [2] argues that software can have as much of an influence on the behaviour of people and society as a whole as law. This idea is a central motivation for this thesis to also study the economic and social environment of the technologies developed. Van Schewick [3] presents a framework to examine the merits of network neutrality. Since this thesis aims at designing an infrastructure that can potentially accommodate a broad range of services, issues of network neutrality play an important role.

Potential Cooperation

As this thesis seeks to take an interdisciplinary perspective, it would benefit from collaboration with researchers from the fields of both law and economics and sociology.

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Interaction Toolkits

Paul Holleis
University of Munich (LMU)
LFE Medieninformatik
Amalienstr. 17
Room 206, 2nd floor
+49 89 2180 4657
paul@hcilab.org
http://www.hcilab.org/paul

PhD-Supervision: **Dr. Albrecht Schmidt**

Doctoral Seminar, Linz, 2006

Abstract
Ubiquitous computing is no longer the playground of hardware specialists and programming geeks only. Platforms and components for hard- and software are readily available to create complex applications. However, this often requires detailed knowledge in several areas like electrical engineering, protocols, programming, etc. Therefore the design process should be supported by tools. In my thesis I try to spot the parts of such processes that can be simplified, verified or automated. This includes the choice of interaction, the choice of hard- and software, deployment, and the evaluation of the resulting system. I also anticipate providing tools that can validate certain properties and show key characteristics of developed applications.

Keywords
Ubiquitous and pervasive computing, interactions, tool support, automation, verification

Problem Statement and Research Question
Researchers in the Ubicomp community are often working with a variety of technologies and techniques. This includes sophisticated hardware devices such as PCs, Laptops, PDAs, mobile phones, etc., as well as small microcontrollers and single sensors. Applications range from simple, contained and centralised to complex, distributed and dynamic systems. Many aspects like privacy, security, complexity, robustness,

user acceptance and user friendliness etc., play important roles in the design of such applications. Such design processes require the commitment of many different types of professions: Market analysts, user interface designers, programmers, mechanical and electrical engineers, to name but a few. Often whole projects are done by people with significant knowledge in only one or two of those areas. All other aspects are neglected, done by inexperienced people or outsourced.

The aim of this work is to provide a system that incorporates knowledge and experiences from a broad range of developers and research to enable others to profit from that and to simplify the development as well as evaluation of applications. This research is supposed to help application developers from various backgrounds to implement their ideas quickly and comfortably, supporting them to avoid common errors and improve efficiency, usability, stability, etc. using expertise from other projects.

This includes support of approaches that have been found very important in standard software engineering. Applications have many interesting characteristics like the longest or average path to navigate a menu to some specific item or the number of different possibilities to initiate a certain action. Knowing such values helps creating better and more robust designs and can often be retrieved automatically. Another significant aspect is the validation of defined properties. It is, for example, in many applications important to ensure that it is possible to navigate back to a main menu from every possible state. Some application behaviour can also be automatically inferred. In [5], for instance, Harold Thimbleby shows an example where matrix algebra can be used to check what happens when a certain button is pressed twice (regardless of the current state of the system) although the designer has only specified the behaviour after one single press.

One of the central questions that I look forward to answering is where exactly people need toolkit support and what features such support will have to provide and what issues it would have to avoid. This implies looking at how to incorporate knowledge and experiences that result from both theoretical and (often not formalised) experimental experiments.

Approach and Methodology

This thesis is done in the context of the research group Embedded Interaction [1]. In the past years, my colleagues and I have conducted several projects using different hardware platforms and a multitude of sensors and actuators. Applications range from self-contained, autonomous learning applications to wirelessly connected ambient displays. This helped to get insight into how such applications are realised and potential problems in the design and implementation phase.

These experiences combined with a careful research of experiences and work done by other researchers in the last years as well as ongoing and planned projects will serve as a basis to extract enough knowledge to be able to understand the process and specify requirements. The design processes and tools found will be compared with those of known software engineering and different steps and tasks performed during that process will be discovered. The next step will then be to identify possible spots for integrating tool support.

To be able to evaluate the usefulness of such tools, each identified possibility will be rated and prototypically implemented. I envision applying those to our own projects as well as letting different user groups try those systems. To get results, some these groups will first try to accomplish a set task without the tool and then with help of the tool. The other half will do the same, only vice versa. This helps to reduce the influence of implicit improvement when repeating a similar task. Experiences will be recorded and differences measured. According to the results there will be one or more iterations on the system.

It is expected to combine theoretical and experimental research using theoretical and experimental results to create an interesting mix of experiences and formal / statistically derived results.

Related Work

There have been and still emerge several projects that develop frameworks and toolkits for application development with different technologies. This includes efforts to combine several programming languages (like in Visual Studio .NET) and general description languages of sensors, actuators and their data (like SensorML [6]). There are also several projects that brought forth toolkits for the implementation of ubiquitous applications:

The ECT Toolkit [2] was developed as part of the Equator project. It features a components and plug-in based architecture. Instances of components are used as nodes of a graph. The interface of each component defines outgoing (events) and incoming edges (operations). Application logic can be implemented by connecting outputs of components with inputs of others. A problem is that the huge number of available (and necessary) components renders the toolkit hard to use. To implement more complex behaviour, complex components offering scripting capabilities are needed reducing the ease of use of the concept. This system assists in quickly prototyping applications.

Our own first steps towards toolkit support build on ideas from the iStuff toolkit [3]. It offers a variety of devices acting as input or output instruments. Each of those communicates with a proxy running on a computer. This computer is connected to a tuple space implementation. All messages sent to / from device proxies or applications are passed through this tuple space. An interesting feature of the toolkit is that an intermediary allows for dynamically remapping events, i.e. events can be redirected to another device during run-time. That system adds, among other things, toolkit support for dynamically exchanging components.

The Stanford HCI Group has begun to use iStuff. Lately they have developed d.tools, an architecture with toolkit support for rapid prototyping. Hardware is assembled using physical controllers, sensors and output devices [4]. The behaviour of the system can be implemented using a graphical editor implemented as a plug-in for Eclipse Development Environment. Users graphically arrange iconic representations of hardware items into a state graph where states specify device outputs and state transitions are triggered by physical inputs. The state graph can become quite complex and confusing even for a small number of buttons etc. It supports constant synchronisation of the software with the available hardware and its states.

Besides support for connecting different components these toolkits do not offer additional assistance with respect to verification, usability, security or efficiency.

Preliminary Results

In our projects, many students have used different hardware platforms and lots of different types of sensors and actuators with various access protocols and communication abilities. I have observed that the first steps in using existing and new devices to create new applications are often quite hard. This can partly be simplified by the toolkits described above. However, I also found that from a higher level point of view, there arise many problems that cannot be solved in this way. Decisions of which interaction technique, which hardware and what values for parameters (like sensor rate, size) might best be used are still to be made by the application designer. Application logic verification and characteristics extraction is not used at all. Although it will not be possible to solve all of these issues automatically, I see great potential to add tool support for many of those aspects.

I am currently in the process of developing a toolkit for interaction applications [7]. It started to provide functionality similar to that of those projects described in the related work. However, I want to incorporate different views and interactions on the same structure to enable different types of users (programmers, designers, prototype implementers) an equally comfortable tool. In parallel, I endeavour to collect necessary information and to design tool support for other stages of design and higher level issues that I identified.

Conclusions and Future Steps

To summarise, I want to define spaces where application development including external hardware devices can be supported with tools. At least prototypical implementations of such tools and their experimental evaluation are planned. This requires gathering and categorizing of users, experiences, technology, design processes, etc. and the application of software engineering processes like validation and evaluation techniques.

I strongly depend on the collection of experiences and knowledge of other researchers and research groups as well as potentially industrial design work. This will provide me with the necessary details of where problems in such processes arise and where and in what extent toolkit support can be provided.

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Design and Implementation of a Generic Coordination Architecture for Mobile/Pervasive Environments

Manfred Bortenschlager
JKU Linz, Department of Telecooperation &
Salzburg Research Forschungsgesellschaft m.b.H.
+43 650 805 1982
manfred.bortenschlager@salzburgresearch.at
www.salzburgresearch.at

PhD-Supervision: **Prof. Gabriele Kotsis**

Doctoral Seminar, Linz, 2006

Abstract
Current middleware solutions combining heterogeneous entities of pervasive environments do not explicitly address the coordination issue and usually represent ad hoc and proprietary attempts. However, by separating the programming from the coordination concerns and providing problem-specific coordination patterns, the development process of pervasive computing systems can be improved through modularity, reusability, exchangeability and extensibility similar to the idea of software design patterns. Hence, this work proposes a generic two-layered coordination architecture particularly aiming at the specific characteristics of pervasive computing environments. This architecture comprises (i) the coordination media layer adhering to the space-based computing paradigm, and (ii) the coordination pattern layer proposing several reusable and problem-specific patterns.

Keywords
Coordination Theory, Pattern-based Coordination Models, Mobile/Pervasive Environments, Peer-to-Peer Networks, Space-based Computing

Problem Statement and Research Question

Pervasive computing environments are considered as physical environments saturated with computational elements and communication technologies. The challenge is to integrate the human users gracefully and to distract them as minimally as possible. In the future, the environments where we will spend our daily lives will contain a network of more or less specialised computing entities that will interact with the users and among themselves [11]. Besides the complexity of social structures - which must not be neglected - such as people and organisations involved and their individual preferences, a great magnitude of heterogeneous, technical entities determines pervasive computing environments. These are represented by small (or tiny), mobile and embedded devices respectively hardware, a variety of transmission technologies, and software and communication paradigms. To assist human beings in managing their daily lives with a minimal user distraction, these "smart" objects equipped with computing and communication facilities have to autonomously interact in the background. Furthermore, to provide the desired mobility of the users - i.e. their unhindered physical motion, seamless and unobtrusive support by the pervasive system has to be delivered.

In order to address this vision of pervasive computing, Satyanarayanan defined the following four research thrusts [17]:

(1) *Invisibility*: All the involved entities are coordinated in the background and hence, the user should be distracted as little as possible. The pervasive computing environment strives for meeting the user expectations and avoids surprising him.

(2) *Scalability*: As argued above, the number of involved entities is increasing. Thus, the frequency of interactions increases too requiring more bandwidth, energy and processor resources. A pervasive computing system has to be able to cope with scalability issues by appropriately coordinating the possibly scarce resources.

(3) *Adaptability*: Pervasive environments are characterised by dynamically changing conditions, due to the required support of mobility. The occurring, usually uneven conditions have to be masked by according mechanisms and by adapting to new situations.

(4) *Effective Use of Services*: In pervasive computing, the physical world and the abstract world of paradigms and concepts of computer science are merged resulting in smart spaces which should offer useful services to users. Here, the term "effectiveness" is used as Peter Drucker, Professor of social sciences and management, refers to it, namely as "to get the things done *right*" [4]. Hence, the opportunities arising from the convergence of physical spaces, human beings and pervasive computing have to be effectively exploited in order to provide real value-added services in an appropriate quality level.

Considering these thrusts and the high number of involved entities, it appears essential to incorporate some form of coordination in order to improve pervasive computing environments. To achieve this, it seems to be promising to separate programming issues from coordination issues [6][9] and consequently, allow for a more modular and standardised way of development. Hence, the hypothesis of the PhD project is stated as followed:

By separating the programming from the coordination concerns and for this, introducing a generic coordination architecture for pervasive computing environments, the invisibility, scalability, adaptability and thus, the effectiveness of pervasive systems can be significantly increased.

In this PhD project, a generic coordination architecture is proposed with the objective to improve the service of pervasive computing environments by addressing the above mentioned four thrusts.

Approach and Methodology

As argued in [18], coordination is based on communication. Hence, two major issues are considered in the design of the coordination architecture leading to a two-layered approach:

Layer 1 - Coordination Media:
In order to address the communication requirements of pervasive computing environments [17][14], the coordination media component (i.e. the communication channels) of the system has been modelled according to the decentralised space-based computing approach (SBC) [10]. SBC is very similar to Linda-like systems [9]. The idea behind this paradigm is to have a commonly shared object space where processes can have access. Objects (i.e. tuples) can be read, stored in or removed from the space. By using this simple mechanism and further inherent spatial, temporal and referential decoupling [5], a great many problems can be addressed in a more elegant and effective way by having the possibility of choosing one of many feasible communication facets as opposed to the C/S approach, which always implies a direct communication. With respect to this layer the Coordinated Shared Objects (CORSO[1]) technology has been deployed.

Layer 2 - Coordination Mechanisms:
Building up on the communication infrastructure of the first layer, the second layer deals with the incorporation of several problem-specific and exchangeable coordination patterns. For this, particular patterns have been modelled to address specific use cases. Eventually, a coordination pattern catalogue is going to be established comprising the following patterns: Supervisor/Worker, Publish/Subscribe, Blackboard-based, Matchmaker, Broker and Negotiating.

The methodology to achieve the objectives of this project can be subdivided into the following parts:

Pre-phase
In this part, potential scenarios[2] and use cases will be identified and the related requirements and relevant coordination patterns will be analysed. A further extensive and targeted state of the art analysis will follow. Furthermore, appropriate test cases for following validations will be specified. Finally, a comparison methodology and reference system will be

[1] See TU Vienna, Prof. eva Kuehn: http://www.complang.tuwien.ac.at/eva

[2] The coordination architecture will be applied to event/emergency scenarios, where the involved people such as responses or guards should be unobtrusively assisted in their coordination process.

designed in order to have a means to compare coordination mechanisms.

Main phase
Two iterations will be conducted in this part of the project. The first one will comprise the software design, implementation, quantitative data acquisition and comparison, a discussion of the outcomes and a proposed incorporation into the next iteration. Consequently, the second iteration is comprised of a software re-design according to the outcomes of the first iteration, implementation of the open issues, quantitative data acquisition and comparison, discussion of the outcomes and composition of recommendations.

Evaluation/discussion
The last part will deal with an evaluation of the outcomes. The final system will be validated by experienced user groups. The overall system behaviour and the feedback of the user validation will be critically discussed. By using the comparison methodology and reference system designed in the pre-phase, a benchmark with other approaches and similar systems will be conducted. The behaviour of the investigated systems will be evaluated with respect to the specified hypothesis of this PhD project.

The methodology chosen will support the proper achievement of the objectives. As mentioned above, the outcomes will be demonstrated by the implementation of a software prototype and validated by users. Eventually, the outcomes of this project will be: a catalogue of specific requirements of pervasive computing environments correlated with adequate coordination patterns, a state of the art analysis of similar approach, a generic P2P-based coordination architecture (design and implementation), recommendations and a critical discussion.

Related Work

In [1], Ciancarini describes a coordination model as a triple of {E,M,L}, where {E} represents the coordinable entities which ask for coordination, {M} stands for the coordination media - representing the first layer of the proposed coordination architecture - and {L} is referred to the coordination laws defining how the interdependences have to be resolved - representing the second layer. Moreover, in [12] the term coordination theory was coined where this issue is considered as an interdisciplinary study. It is concerned with properly defining the coordination concept in a domain-independent way and with elaborating generally applicable mechanisms and patterns. Hence, Malone and Crowston defined coordination as "managing dependencies between activities". It is argued that coordination only makes sense where tasks are interdependent. In fact, it can only occur in situations where this is the case. This definition seems to be sound and is applied to this research, too.

With respect to the first issue, initial research efforts were conducted in 1985 in the domain of parallel computing. Linda [9] was the result as the first system using a central tuple space in order to store and distribute data. It was proposed that coordination has to emphasise a high degree of decoupling among computing entities. The participants share information stored in a globally accessible, persistent data store, typically implemented as a centralised tuple space. The main difference of this system compared to the CORSO framework is the server-based architecture representing a bottleneck and hampering flexibility. CORSO, however, is a Peer-to-Peer technology with replication mechanisms, which makes it completely decentralised. Furthermore, due to the small footprint of its kernel, it is possible to deploy it on portable devices such as mobile phones, PDAs, notebooks or embedded systems. All these features make CORSO a light-weighted, highly dynamic middleware perfectly suitable for P2P and mobile ad hoc networks.

The second issue - the coordination mechanisms - touched in this paper, has also been intensively investigated within the research field of Artificial Intelligence (AI), and there particularly in agent technology [15], where four basic coordination concepts were identified: organisational structuring, contracting, multi-agent planning, and negotiation. These concepts and other research papers [3][2][7][16] about coordination mechanisms have served as a basis for the establishment of the coordination pattern catalogue which will be introduced in this PhD project.

Preliminary Results

In pervasive computing systems, real world objects are monitored by sensors and the real world, in turn, is notified respectively modified by actuators [6]. The rules which determine this process and the reactions are defined within a middleware. This architectural component is responsible for the behaviour of the whole system. Hence, this would be the right place to incorporate pattern-based coordination models which can be applied to specific problems. Current solutions do not explicitly deal with the coordination issue. Usually, these solutions provide ad hoc coordination means and thus, represent not reusable proprietary approaches [13]. Due to the fact that programming concerns are not separated from coordination concerns (pattern-oriented coordination models) reusability, modularity, exchangeability and extensibility can not be exploited. Hence, these proprietary solutions are far from ideal. Characteristic shortcomings resulting from inappropriate coordination would be a high number of message exchanges (i.e. communication overhead), incompatibility, inconsistency, tight couplings (in space and time) and thus inflexibility, low performance, and finally ineffectiveness [3]. The idea of this PhD project is to design and implement standardised coordination patterns very similar to the idea of software design patterns [8] where a three-part rule expresses the relation between a certain context, a problem and a suitable solution. The proposed coordination architecture will provide a modular way of applying coordination patterns to specific coordination problems in such environments. The inappropriate way of addressing the coordination issue in current pervasive computing systems offers a significant field of improvements. Due to the approach presented in this paper, the PhD project contributes to the pervasive computing community by incorporating the methods and means of the interdisciplinary study of coordination into the field of pervasive computing.

Until now, a prototype implementing the supervisor/worker pattern using CORSO for the coordination media layer was realised. To simulate a pervasive environment, it was deployed on mobile devices (i.e. two Nokia 6630 and an IBM Thinkpad) which communicated via Bluetooth.

Conclusions and Future Steps

The next step will be to conduct an extensive state-of-the-art analysis where the potential benefits and drawbacks of other coordination middleware systems will be investigated. In parallel to that, the prototype will be extended by implementing more patterns and the possibility to choose between several transmission technologies (e.g. WLAN, 3G, IrDa, or RFID). Subsequently, those approaches will be compared with the proposed architecture by deploying the comparison methodology.

Feedback on the proposed architecture and methodology, refinement advices and hints on peculiarities of experts within the field of pervasive computing may be very helpful at this stage of the PhD project.

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Stigmergic Systems in Pervasive Computing

Michael H. Leitner
Johannes Kepler University Linz
Altenberger Straße 69
+43 732 2468 8518
michael.leitner@jku.at
http://www.pervasive.jku.at/About_Us/Staff/Leitner/

PhD Supervision: **Prof. Dr. Alois Ferscha**

Doctoral Seminar, Linz, 2006

Abstract
Stigmergy is a concept of coordination via indirect communication which has been derived from social insects. As there are different interpretations, this outline tries to give a first clarification of this term and its fundamental concepts. This includes the characteristics of stigmergy in nature, as well as a taxonomy with two dimensions (marker-based/ sematectonic and quantitative / qualitative). Next, stigmergic concepts in nature and society will be investigated in detail, as well as the application of stigmergy to pervasive computing.

Keywords
Stigmergy, Emergent Behaviour

Problem Statement and Research Question
The central topic of this thesis is the usage of stigmergic systems in pervasive computing. The goal is to build self-organizing and self-coordinating systems, which are based on the aspect of communication via the local environment. For this purpose, the concepts of stigmergy in nature and society have to be investigated and to be adopted for applying them to pervasive computing. Another point of interest are the possible fields of application, both between human and computer, as well as between humans themselves.

Approach and Methodology

The work will start with an analysis of related work and literature in the field. Because of the different definitions and interpretations of the term stigmergy, it is necessary to clarify the term itself and its fundamental concepts. The application of these concepts to pervasive computing will be done in a further step.

It might be also interesting to extend the CON Framework developed at the Department for Pervasive Computing in cooperation with Siemens towards a stigmergic system.

Introduction to Stigmergy

Stigmergy was first described by Pierre-Paul Grassé (1895-1985) in 1959 [7] and describes the way how social insects coordinate their actions via indirect communication mediated through the local environment. Grassé introduced this term to explain the behaviour of termites; however this concept can be applied for various social insects [6]. The original definition (in French) and its translation are as follows [8]:

“La coordination des tâches, la régulation des constructions ne dépendent pas directement des ouvriers, mais des constructions elles-memes. L’ouvrier ne dirige pas son travail, il est guidé par lui. C’est à cette stimulation d’un type particulier que nous donnons le nom du STIGMERGIE (stigma, piqûre; ergon, travail, oeuvre = oeuvre stimulante).”

[The coordination of tasks and the regulation of constructions does not depend directly on the workers, but on the constructions themselves. The worker does not direct his work, but is guided by it. It is to this special form of stimulation that we give the name STIGMERGY (stigma, wound from a pointed object; ergon, work, product of labor = stimulating product of labor).]

The original article also concludes an English summary: “The stimulation of the workers by the very performances they have achieved is a significant one inducing accurate and adaptable response, and has been named stigmergy” [7].

This concept was used to create a coherent explanation of the *coordination paradox*, which can be observed between the individual and societal level: When looking on a group of social insects, they act in an organised, coordinated way, whereas when looking on the individual, it seems that the single insect does not interact and works solitarily. However, the insects interact indirectly via artefacts or pheromones [11]. The effects of these local interactions between the insects produce as a consequence a certain behaviour of the colony as a whole [3] [4]. This phenomenon is called “emerging behaviour”, as well.

So stigmergy provides a mechanism allowing a robust self-organising environment to coordinate and structure itself through the activities of the entities within the environment in a highly decentralized manner [3] [8]. The individual entities do not have particular problem solving knowledge [3].

In [13] it is stated based on an annotated bibliography [12], that there is no single universally accepted definition: Self-organization and stigmergy can be also seen as distinct but complementary concepts [5].

The term stigmergy is derived by the two roots "stigma" (stimulus/incentive) and "ergon" (work) – so its meaning is "incitement to work by the products of work" [3] [8]. Other authors [10] refer to sigma as "sign" and identify the following scheme:

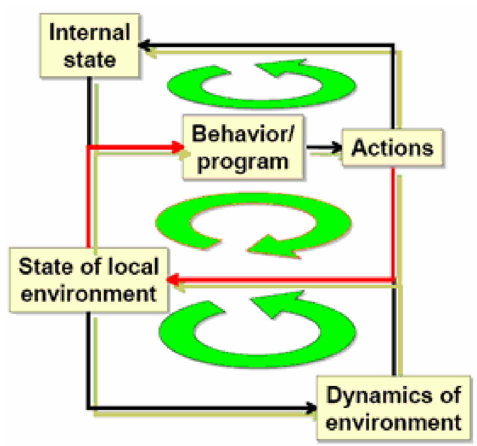

Figure 1: General stigmatic schema [10]

Stigmergy in nature is characterized by the following aspects [10]:

- No central planning
- Indirect interaction through the environment
- Simple individual rules
- Complex adaptive behaviour

In [11] important aspects based on the original definition are mentioned: First, the environment plays an important role. Instead of a passive landscape, it acts as a mediator and ruler of interactions. Second, stigmergic interaction is always mediated; it occurs locally to the interacting entity, and directly affects the environment in some way. Last, the environmental changes are limited to specific elements, e.g. chemical traces in the form of pheromones or artefacts like a chunk of material for nest construction. In addition this paper also mentions three standard types of stigmergic processes, namely diffusion (spreading of e.g. information), aggregation (transformation and combination of several single entities), and selection and ordering.

So stigmergy is a highly decentralized mechanism of coordinating a system by communicating by modifying the local environment. There are two kinds of stigmergy, namely sematectonic and marker-based. When using the first, the current state of the task influences the system's behaviour, only domain-specific elements are used for the stigmergic effect. When using the latter, the system makes use of a task-independent artifical marker which influences the behaviour [10].

Orthogonally to this classification, stigmergic effects can be categorized into quantitative and qualitative ones [1] [5] [10]. The first kind is characterised by the effect of an increased probability of eliciting the same response from other individuals, when the stimulus varies in a quantitative manner. This can be the exact position, strength, frequency, latency, duration, or any other parameter of the action [8]. The second mechanisms also includes this stimulus-response scheme, however the stimuli differ in a qualitative way and can elicit different responses. In contrast to the first type, qualitative stigmergy does not include positive feedback. [1] In addition, a previous action at a specific location might not have an influence on the action (response) both in a quantitative as well as in a qualitative way, but it might influence the outcome [8].

The following table shows this taxonomy of Stigmergy [10]:

	Marker-Based Artificial signs inserted in the domain	**Sematectonic** Domain elements only
Quantitative Scalar quantities	**Gradient following in a single pheromone field**	**Ant cemetery clustering**
Qualitative Symbolic distinctions	**Decisions based on combinations of pheromones**	**Wasp nest construction**

Afterwards some classical examples for stigmergy observed in nature are given [9] [10]. By using pheromones, ants construct networks of paths between their nests and sources of foods:

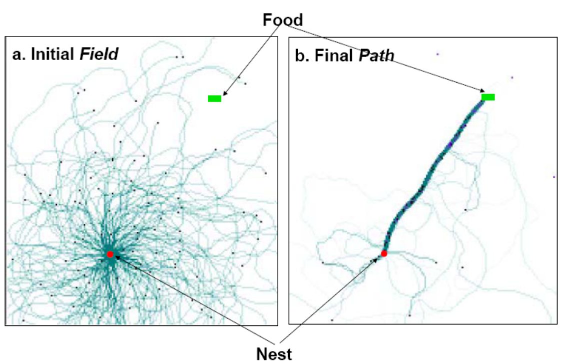

Figure 2: Formation of paths by ants [10]

Another example in nature is the sorting of larvae, eggs, cocoons, and food in ant nests:

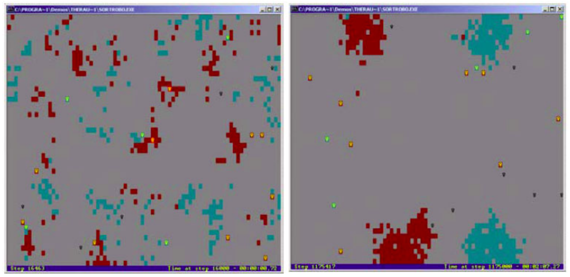

Figure 3: Sorting in an ant nest [10]

Further examples are the nest building of termites, the differentiation of tasks of wasps, flocking of birds and fish, and how wolves surround a prey.

However, there are also examples for stigmergy in pervasive computing: In [3] a pervasive application with small devices with limited resources is described, using the common medium of the environment for indirect communication. In this application context information from environmental sensors and other entities are used for providing this medium.

Related Work

Related fields are organisation, self-organisation, and emergence [10]. Another related field is Multi-Agent Systems (MAS), which can use similar approaches [2] [9]. In [11] it is mentioned, that regarding MAS a wide and coherent view on stigmergy is necessary, as agents are cognitive entities and not like ants, and that the environments in such systems are in general more articulated than a mere pheromone container. A further related field of research is Swarm Intelligence.

Conclusions and Future Steps

This outline gave a first overview over the term stigmergy and its fundamental concepts. However, this introductory step into the field is not completed; it will be necessary to do further research. After the investigation of stigmergic concepts in nature and society, the next steps will include the application of stigmergy to pervasive computing.

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Session 4: Smart Environments and Novel Forms of Interaction

Interaction in Dynamic Smart Environments

Robert Adelmann
ETH Zurich
Clausiusstrasse 59, IFW D43.1
+41 44 632 20859
adelmann@inf.ethz.ch
http://people.inf.ethz.ch/adelmanr/

PhD-Supervision: **Prof. Friedemann Mattern**

Doctoral Seminar, Linz, 2006

Abstract
I'm still in the process of choosing a more focused research topic. The field I'm currently looking at is probably best described as HCI in smart environments (augmented reality, tangible interfaces, ambient displays) and context awareness (with a focus on localization). Other topics are mobile applications and mobile phones, with their increasing capabilities and wide availability.

Keywords
HCI, localization, augmented reality, tangible UI, ambient displays, mobile phones

Problem Statement and Research Question
With the disappearing of devices into the environment and their increasing heterogeneity, traditional WIMP-schema (Windows, Icons, Menus and Point Device) based interaction is no longer effective or feasible. The general research problem I would like to address is how an intuitive and effective interaction for some tasks in smart environments can look like.

Another interesting research area is given by the fact that there is already an abundance of information available online, but having access to the desired information in the ”right” situation can be a real challenge. Given the increasing capabilities and the high availability of mobile phones, there is a lot of potential in this field.

Approach and Methodology

In a first step, use cases and interaction requirements in certain smart environment settings should be identified. After a theoretical definition of interaction concepts, the fundamentals for experimental systems should be laid by building some basic software and hardware components. These components are then used in order to assemble prototypical systems. The quality of research will be validated and evaluated using these prototypical implementations in user studies.

I think this approach is appropriate, since ultimately it is only possible to evaluate how close we are to the set goal of an intuitive and natural interaction by including the key factor: humans. Another reason for this approach is the fact that technological capabilities are a major factor for the frame of possibilities in the field of HCI.

Conclusions and Future Steps

Future steps will include the exploration of interaction concepts using the above mentioned approach and the implementation of some prototypical applications based on mobile phones and on-site information access.

Additional experience would be required regarding user studies.

Interaction Techniques for Continuous Information Spaces

Otmar Hilliges
Univeristy of Munich
Amalienstrasse 17 80333 Munich
+49 89 2180 4687
otmar.hilliges@ifi.lmu.de
https://wiki.medien.ifi.lmu.de/view/Main/OtmarHilliges

PhD-Supervision: **Prof. Andreas Butz**

Doctoral Seminar, Linz, 2006

Abstract
When computers move beyond the desktop, they enter our working and living environments. A continuous information space is overlaid to the physical space. Interaction in such a space can involve physical as well as digital objects and new techniques are needed to account for this mix of physical and digital world. In my work I try to investigate and propose new interaction techniques for interaction with multi media content in environments that mix physicality and virtuality.

Keywords
Multi-User Large-Scale Displays, Interaction Techniques, Hybrid Widgets, Bi-Manual Interaction, Immediate Interaction.

Problem Statement and Research Question
Along with the introduction of ubiquitous technology in our everyday live, an increasing mismatch of requirements and availability of interaction styles and techniques can be observed. While display and sensor techniques develop further away from the desktop settings, the interaction techniques frequently used are merely adaptations of the traditional WIMP paradigm. A different style of thinking about systems that are embedded in our environment is needed to come up

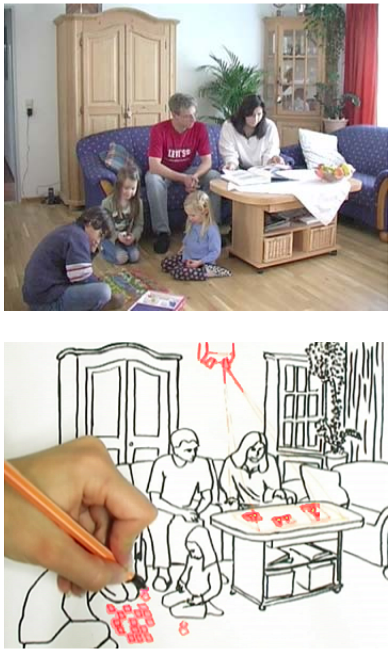

Figure 1: Continuous information spaces blending into the home environment.

with interaction styles that match the requirements implied by such systems.

In my research I try to address two main issues. 1) I try to establish a mental model for interaction in instrumented environments and their perception by users. 2) I try to investigate and propose new interaction techniques that are specifically suited for domestic environments (enhanced by ubiquitous displays) and multi-media content (e.g. pictures, music, video).

In Instrumented Environments such as the FLUIDUM [1] instrumented room a large number of displays in various dimensions and resolutions are built into the fabric of the users' surroundings. Among them table-top, wall-mounted and projection based displays. In addition, different mobile devices such as handheld computers or tablet PCs are used frequently.

As technologies will become, in practice, more present in our daily lives, they should also be physically less obtrusive and integrated into our environments in a natural way. This can, for example, be accomplished by incorporating them into home interiors, such as the very walls of a house; or furniture, for example, enabling a coffee table to double as an interactive display area (see Figure 1).

Emerging Challenges within Continuous Information Spaces

The various display technologies built into the fabric of our everyday surroundings are not only distinguished by type, size and capabilities (e.g. electronic ink, table-top displays or projection) but also by the way in which they are related to each other and used by the inhabitants. They require a different approach for presenting, accessing and manipulating information. Two problems are obvious: 1) Displays built into our every day environments lack the standard input controls desktop systems offer. 2) It is problematic to still think of single display units, since we expect information to spread over a range of devices. Instead I propose to consider the whole environment as a *continuous information space* where physical and virtual information blends into each other.

A number of technical assumptions which are valid for desktop screens, become inappropriate in *continuous information spaces*. One of these is the assumption of a limited and well defined screen real estate, which makes controls (e.g. start menu) with globally fixed positions a good idea. If walls and tables become displays and users roam the area, it makes more sense to adopt the users' relative coordinate system and provide menus (or whatever their equivalent will be) to the user where appropriate.

A second implication of multiple users sharing displays and information is that information cannot be manipulated on a global scope by one user without potential interference with the interests of other users. Hence data manipulation should be limited to a local scope without restricting collaboration amongst users.

Another invalidated assumption is the single-user paradigm. *Continuous information spaces* are inhabited by many people and several of them will interact with the superimposed information simultaneously, either in collaboration or concurrently. On the desktop, only one person can interact with a standard PC and all the other collaborators are degraded to merely follow the leaders' actions. New interaction paradigms, enabling parallel interaction, have to explicitly support collaboration. The inhabitants of a continuous information space share resources and interact with them in a truly parallel way. They might work concurrently or occasionally join their efforts to reach common goals.

The current interaction with desktop PCs and their GUIs is mostly goal-driven and office- or work-related. Thus, efficiency is a major criterion for its evaluation. *Continuous information spaces*, in contrast, will enter our daily living environments. They need to support informal use and will be assessed on additional qualities beyond efficiency and usability. Visible objects as well as physical artifacts might have to be decorative, enjoyable or likable.

Approach and Methodology

I plan to conduct my research on both levels, theoretical and practical where the practical part is clearly dominant. But I have a strong background (and interest) in psychology which I try to use for some interdisciplinary projects and collaborations.

In the near future I plan to build several prototypical systems using an iterative rapid prototyping approach and agile software development methods. I see the biggest problems in terms of validation and evaluation because my work focuses strongly on aspects that are very hard to assess e.g. enjoyability, likeability, fostering of communication and social implications.

Related Work

In order to support simultaneous input on a shared information space, one needs to cope with two main issues: 1) enable users to simultaneously open a personal working area and interact with information within the shared referential information space; 2) free users from spatially pre-defined interactive areas.

With the peephole metaphor [2] a conceptual model for information overlaid to physical spaces has been described. Each unit of information has a specific position in space. Although information units might reside all over the environment, they only become visible within restricted areas, the so-called peepholes. Peepholes can be system-initiated (e.g. through a steerable projector) or user-initiated (e.g. by putting a mobile display in a certain location).

Guiard [3] introduced a model for integrated, skilled bi-manual interaction, called the kinematic chain. Where 1) the two hands form a serialized chain of two abstract motors and the motion of the non-dominant hand is the input for the dominant hand's motion. Thus the one hand serves as a reference point for the other hand's movement. And 2) both hands have different roles and skills. While the non-dominant hand mostly initiates interactions and positions the actions' context (e.g. the paper in handwriting), it is, in general, less skilled for fine-grained work. In contrast, the dominant hand is superior in executing tasks on a finer scale.

The Toolglasses/Magic Lenses technique [4] allows users to retrieve different visual representations of the data within defined portions of the visual information. It is a metaphor for holding a drawing palette with one hand and using a brush with the other.

Based on this insight several interaction techniques have been developed that make use of our trained

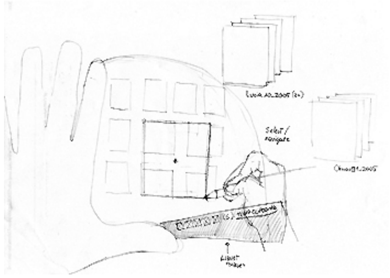

Figure 2: Mock-Up of a personalized interface for shared media collections

everyday skills. However, all of them are geared towards single-user, single-display setups and do not account for the specific requirements that arise with shareable instrumented environments.

The proposed technique is a direct descendant of the Toolglass[4] and Peephole metaphors but it is specifically tailored towards multi-user and multi-display environments.

Preliminary Results

I try to address the issues outlined above by utilizing *personalized interfaces* (Figure 2) as views onto *continuous information spaces*. These interfaces are portable and can be freely positioned by each user. Currently I plan to use physical handles which, upon contact with a display surface, extend into a virtual, semi-transparent overlay. Thus they serve as a reference point both for perception and cognition as well as for interaction.

First of all can we address the spatial limitations with which traditional menus have to cope. Since every user has her own personalized view all controls she needs are always in place and the actions can be applied in a fluid manner. In contrast to WIMP controls no additional movement of the hand (to and from a menu) is necessary. Also the positioning, orientation and order of access problems can be addressed by personalizing the controls instead of having a centralized menu. Even more important is that the current task does not have to be interrupted in cognitive aspects by changing the mode of the application, but instead every action is carried out in place by clicking through the control. Thus making the action mentally more integrated and coherent.

Second, the concept of personalized interfaces can support collaboration by offering explicit ways of communication. In the same manner as the one hand is a reference frame for the other, the personalized interface can serve as a reference frame for communication as well. The position of one's workspace gives clues to others what the current task is, and also helps them understand which parts of the information are currently being contemplated.

Conclusions and Future Steps

Currently the described approach is in a very early stage. I have explored some ideas with paper prototypes and interactive mock-ups. During the next few months we will gradually implement and evaluate the described approach in different scenarios and settings, starting with a picture-browsing scenario. Other scenarios include browsing, organizing and annotating other kinds of multimedia collections (e.g. music, videos). A critical piece of my work will be to learn new assessment and measurement methods for the so called soft-features of the described settings.

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Gaze Tracking for HCI

Heiko Drewes
LMU Munich
Amalienstraße 17, 80333 München
+49 (089) 2180 - 4650
heiko.drewes@ifi.lmu.de
www.ifi.lmu.de/~drewes

PhD-Supervision: Dr. Schmidt / Prof. Hußmann

Doctoral Seminar, Linz, 2006

Abstract
Digital camera devices are getting cheaper at better resolutions. So video based gaze tracking will be soon available for nearly no costs. There is hope in the HCI research community that gaze tracking can become a new interaction modality for the future.
My research tries to find out how the users can benefit from this technological development.

Keywords
Gaze tracker, multimodal interaction.

Problem Statement and Research Question
Nature designed the eye as an input channel for visual information and the eyes do a lot of unconscious movements. It is not clear how much additional control tasks can be put on the eyes.
With the gaze as a pointing device the users could get rid of the mouse, which is a big advantage especially for mobile devices. Gaze input also promises to be really fast.
The questions of my research are: How can gaze tracking assist the user? Can gaze tracking be a substitute for pointing devices? Can gaze tracking make the computer work more comfortable?

Approach and Methodology
A commercial gaze tracker was bought by the university. It has an application programming interface,

so testing environments for measurements and prototypes of gaze-aware applications can be developed. Testing environments and prototypes are used to conduct user test.

The development of prototypes proofs something is possible. User tests can measure benefits and acceptance. There is no way to avoid prototypes and user tests.

Related Work

Research on eye movements exists for already hundred years, but mostly done by psychologists. A good overview on gaze tracking for HCI is given in: Eye Tracking Methodology: Theory and Practice [1].

The scientific work done up to now was influenced by Zhai's MAGIC Pointing [2]. Zhai et al. suggested placing the mouse cursor at the gaze position in the moment of a first mouse move after text input. The deliberate use of the gaze position avoids the Midas touch problem.

Another research field was inspired by Campbell's reading detection [3]. The algorithm introduced makes it possible to create message boxes which disappear after being read or which have to be read before it disappears.

Preliminary Results

In my first experimental setup the mouse move in Zhai's MAGIC Pointing was replaced by a mouse touch. The initiated mouse movement causes a overshooting of the target which can be solved by a touch sensitive mouse.
Users feel comfortable when setting the mouse cursor with the gaze and a touch sensitive mouse. They believe to be faster with the eyes even if they aren't.

It seems there is a mental notion of the position of the mouse pointer like there is a mental notion for the position of the hand. To hit a target the gaze and the mouse move independently to meet in the target.

Conclusions and Future Steps

The experiments done with the gaze tracker and a touch sensitive mouse were encouraging. The next step will be to use a sensor or a key on the keyboard.
The aim is to find out which feedback for the gaze position is appropriate and how to interact with the standard widgets like a scrollbar.
If this all works, the vision of a computer without mouse is close to reality.
It would be nice to cooperate with scientist investigating novel interaction methods and especially doing research on gaze tracking hardware and algorithms, for example for outdoor use.

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Intuitive Metaphors for Interacting with Mobile Computers

Heinrich Schmitzberger
Institut für Pervasive Computing
Johannes Kepler Univeristy Linz
Altenbergerstr. 69
+43 70 24 68 13 40
heinrich@pervasive.jku.at
www.pervasive-computing.at

PhD-Supervision: **Univ.-Prof. Dr. Alois Ferscha**

Doctoral Seminar, Linz, 2006

Abstract
Since PDAs, mobile phones and portable multimedia players have become our constant companions in every day life we are experiencing difficulties interacting with these devices. Though we've grown accustomed to desktop computing user interfaces these metaphors unfortunately don't apply to the needs of mobile computers. It seems quite obvious that the increasing of portability leads to a decreased usability.

The aim of my thesis consists in finding novel methods for interacting with mobile devices making them easier to access while safer to operate. My research focuses on both input and output methods as well.

Keywords
Mobile computing, gesture tracking, handwriting recognition, human-computer interaction, everywhere displays.

Problem Statement and Research Question
As Fukumoto stated in [1], there are three factors required for mobile computing devices: "Portability", "Usability", and "Constancy". First of all mobile devices need to be compact and light weight. Additionally they must be easy and intuitive to use despite their small

size. And finally they need to be able to handle continuous interaction with their user.

These requirements are hardly met all at once down to the present day. While modern mobile devices satisfy the demand for portability, their user interface is unintuitive and cumbersome restraining their potential. My research work therefore concentrates on two major issues.

As first issue the means of data input must be addressed. Conventional input metaphors as typing on downsized keyboards or pointing via stylus have proven inconvenient. The bigger the amount of data we want to input the longer it will take us while frustration towards mobile computing devices evolves. If we want to improve consumer acceptance it is necessary to identify the methods that users understand as most intuitive. To guarantee usability we must make use of metaphors in mobile computing that have approved in real life interaction.

The second problem is posed by the very limited amount of screen space on which to display information. As a matter of fact, vision plays the most important role when it comes to perceiving information. However, physically enlarging the screen would contradict the portability constraint as the devices must be able to fit into the hand or pocket to be easily carried. Therefore novel approaches of extending the limited displays of mobile computers need to be developed.

Reflecting on the issues mentioned above my claim to this field of research can be described as follows: mobile computing needs to make use of new metaphors and interaction techniques that abstract the inconveniences of mobile solutions while concentrating on the fundamental aspect of making information portable and accessible - anyplace and anytime.

Approach and Methodology

I conduct my research on an experimental basis. Fundamentally I try to explore conventional interaction methods of people with all kinds of devices and things of daily use identifying the intuitiveness of their action. I furthermore intend to draw conclusions on the acceptance of the metaphors that appear.

I'm approaching my topic based on the thought that the only broadly acceptable means for intuitive human computer interaction must arise from the way we are dealing with things we don't perceive as technology in everyday life.

To validate the quality of my research contribution I will have people working with several prototypes derived from the most usable and intuitive metaphors determined by my work. If a user is confronted with a new interface the most appropriate way to determine its suitability is the measurement of time the user needs to handle it right. I claim that the more the user is familiar with its basic handling metaphor, the quicker he will be able to operate it.

Related Work

In the following I try to summarize briefly the publications that influenced my work so far.

First to be mentioned in this section is the work by Lumsden and Brewster [2] in which a paradigm shift from usual mobile computing towards multimodal interaction techniques is proposed. Their work demonstrates the feasibility of alternative interfaces which use hand and head gestures for input combined with audio feedback. Further to be mentioned is an earlier contribution from Brewster [3] in which he identifies the problem of the lack of displaying space on mobile computers.

Investigating different possibilities of interacting with mobile computers I mainly focus on gesture recognition. In their publication from 1987 [4] Zimmerman et al. explored the Data Glove, a device integrated in a glove that provided real-time gesture, position and orientation information. Based on this early idea Tsukada and Yasumara presented the "Ubi-Finger" [5]. This work introduced a portable input device to be applied to the index finger enabling its user to operate several electronic devices (such as a PDA or a stereo) by intuitive hand gestures.

A different while impressive approach to the topic of hand gesture tracking is stated by [6]. In this publication a smart laser-scanner is described. This device is capable of tracking hand and finger gestures posing in not yet portable but interesting alternative to ordinary keyboard/mouse input.

Preliminary Results

As my contribution to this field of research I try to proof that the increase of usability need not lead to a decreased portability. Therefore the mobile computing device has to vanish away from the user's field of perception becoming a back-end for data input/output. I want to show that it is possible to interface with mobile computers by very intuitive and inconsiderable means making use of resources that haven't been considered as such yet.

Conclusions and Future Steps

To accomplish my goals I have to investigate "human non-computer interaction". In this area some research has already been done. I currently focus on identifying hand gestures and the recognition of handwriting, dealing with problems such as tremor cancellation.

As I am at the beginning of my research in this area I would welcome additional expertise when it comes to the sensory evaluation of gesture tracked data. I am currently working with inertial sensors and have already encountered several difficulties with the products on the market.

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Integration of Olfactory Media and Information in Pervasive Environments

Bernadette Emsenhuber
University of Art Linz | Johannes Kepler University
Altenbergerstr. 69
+43 732 2468 8526
bem@pervasive.jku.at

PhD-Supervision: **Karin Bruns | Alois Ferscha**

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Abstract

The most important requirement to a pervasive environment is to make technology invisible, but also inaudible, inodorous for the user. This means that a pervasive environment must appeal all five senses to hide technology by a real, augmented world. Aromas and Flavours could also transport information like pictures or sounds. But they need a different way to integrate and use them in a pervasive environment.

Keywords

Olfactory, Pervasive computing, media, information, perception, information design

Problem Statement and Research Question

Nowadays pervasive environments often appeal only two senses, the sense of hearing and the sense of sight. Sometimes the sense of touch is considered, but the sense of smell and taste are omitted. This makes such environments unreal, because information for one sense isn't supported by the information for other senses (e.g. information for the eyes isn't supported by information for the nose). So there is no multimodal communication between the environment and the user.

Smells and Odours are information which is interpreted most individually. The same information content (e.g. smoke) has a different meaning for different users (e.g. a house burns, warming open fire, someone smokes,…). So following research questions need to be answered:

How do users perceive odours and is there a possibility of an objective perception?
The psychological research found out that people perceive odours very differently. But there are some smells which are always interpreted in the same way, e.g. stink is bad and perfume is good. Besides odours has a bigger effect on the human mind as pictures or sounds. *So how far could people be influenced by odours?*

Smell has been an unconscious media so far. But is it possible to use smell conscious?
A selective use of smells could effect individual or mass reactions. *So could smell be used as mass media?*

How could the perception of odours be used for a standardized communication between user and user or user and environment? Is this possible? This depends also on the human perception of odours. Further the current and future technical possibilities plays a big role.

How could an olfactory communication be integrated in a pervasive environment?
Considering the rules how technology should be hidden in a pervasive environment olfactory technology could be integrated. But there are also other aspects like proportion or the local and temporal limitation of odours, which must be considered.

Approach and Methodology

The experimental research bases on projects of the department of pervasive computing and polytechnical university of Hagenberg.

The research results will be evaluated by applying these to future installations of the department of pervasive computing and the polytechnical university of Hagenberg.

Related Work

Papers

German Literature
Jürgen Raab, Soziologie des Geruchs, Uvk, 2001

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English Literature
Constance Classen, Antohny Synnott, David Howes, Aroma: The Cultural History of Smell, Rotledge, 1994

Linda Bartoshuk, Carterette, Gary K. Beauchamp, Tasting and Smelling, Academic Press Inc. (London) Ltd, 1997

Catherine Rouby, Benoist Schaal, Andri Holley, Danihle Dubois, Remi Gervais, Olfaction, Taste and Cognition, Cambridge Univ Pr (Sd), 2002

Deborah Roberts, Andrew J. Taylor, Flavour Perception, Blackwell Science (UK), 2004

Preliminary Results

In 2002 the polytechnical university of Hagenberg realized an augmented reality installation (Smellware) with an integrated smell machine (Smellbox). Test shows that a overload of odours causes a physical and mental refusal.

Conclusions and Future Steps

Next step is the theoretical research in the subject areas usability, perception and design to delve how far design rules of these topics could be applied to pervasive installations.

This thesis is written in media theories. Main supervisor is Karin Bruns of the University of Art of Linz. Because of the main research it needs a co-operation with the polytechnical university of Hagenberg and the department of pervasive computing with Alois Ferscha as co-supervisor.

Smart Environments and Universal Access

Steve Hinske
ETH Zurich
Institute for Pervasive Computing
Haldeneggsteig 4
CH-8092 Zurich, Switzerland
+41 44 632 04 34
steve.hinske@inf.ethz.ch
http://people.inf.ethz.ch/hinskes/

PhD-Supervision: **Prof. Dr. Friedemann Mattern**

Doctoral Seminar, Linz, 2006

Abstract

Future smart-environment scenarios predict a fundamental change in human-computer interaction. The development of new classes of interaction techniques is not limited to business applications but rather affects all areas of our lives (e.g., at home, in the car, etc.). My main interest is to enable just about any user to interact with smart environments, i.e., without regard to his or her age, skills, or experience (thus, “universal access”). This especially includes the consideration of so-called fringe groups which are often neglected.

Keywords

Living and interacting in a smart, augmented environment; HCI; ubiquitous computing

Research Interests

I am interested in how human beings might live in future smart environments and how they can benefit from it.

This is not necessarily limited to already well researched scenarios in the fields of business (applications) but rather concentrates on areas of everyday living. Another important aspect is the inclusion of often neglected fringe groups such as children, the elderly and challenged people.

A main objective is to develop and evaluate interfaces for HCI in smart and augmented environments for all possible target groups ("universal access").

In this context, I intend to cover the following (admittingly large) research areas with focus on specific topics to be determined yet: learning, living, and playing in Ubicomp environments. Learning and playing are already covered by the terms "pervasive learning" and "pervasive games", respectively. 'Living', however, covers several topics, for example "ubiquitous health" or "augmented living rooms".

Besides a technological perspective, I also plan to take social issues into account.

Approach and Methodology

Above all, my approach is rather broad than deep, looking at issues from several angles and point of interests. The goal is to look at possible short- and medium-term future scenarios.

I see two different approaches to this end: the development of new scenarios and, thus, new interactions techniques on the one hand; and, on the other hand, the improvement of already existing ideas and solutions in order to better support a wider variety of users. Both approaches require me to get an overview of existing approaches and technologies and to further identify and find current problems and weak solutions.

Conclusions and Future Steps

My first step is to accumulate information about current ideas, approaches and technologies that have a direct impact on human beings. This especially includes HCI ("how do we interact with a smart environment based on ubiquitous computing?").

Second, I would like to select several topics for a closer examination. Currently, I intend to further research on ubiquitous learning, pervasive games, u-health, RFID end-user applications, smart environments / ambient intelligence, internet of beings. Potential technologies are RFID/NFC, UWB, orientation systems, and others.

Third, I plan to develop some prototypes and applications in selected areas. Consequently, I would like evaluate and assess these solutions in terms of acceptance and usability (mainly based on user studies).