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Potentials of pervasive computing in highly interactive workplaces

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ABSTRACT: The current developments of mobile and pervasive computing significantly change the perception of information and communication technologies. As mobile devices get smaller and wireless broadband networks become available, the vision of having computing facilities anytime and everywhere becomes attainable. This allows the development of completely new areas of applications, especially in industries where there have been great obstacles in using traditional, stationary IT infrastructure. This paper focuses on applications and technologies that can be applied in industrial laboratories, as to be found for example in the chemical or genetic industry. In these laboratories, workers have to perform sophisticated experiments at frequently changing workplaces, requiring a lot of interaction between the workers and between the workers and the laboratory devices. In this paper, we present a systematical approach leading from existing virtual laboratory applications towards pervasive laboratories, thus providing potentials for enhancing interactivity, optimizing work processes and adding value to these kind of workplaces.

1 INTRODUCTION

The objective of the "Ambient Intelligence", which is supported by the pervasive integration of intelligent devices in the surrounding environment (Weiser 1991, Abowd & Mynatt 2000), together with the rapid developments in the area of mobile communications are two major trends which have advanced the ways services for individuals can be designed. New application scenarios are supported by the ongoing miniaturization of electronic circuits, the increase of computational power and the fact that wireless broadband networks are becoming both technically feasible and financially affordable.

The seamless integration of components and technologies into new concept designs enable mobile and pervasive computing technologies to develop innovative applications in many different engineering domain areas such as the design, construction, deployment and support of processes (Garlan et al. 2002, Rebolj et al. 2001). The potentials offered can overcome the restrictions imposed by fixed IT infrastructures. Intelligent working and living environments can offer individuals context-sensitive and personalized services and enhance their work and everyday life experience (Satyanarayanan 2001).

This paper focuses on the different aspects of development and deployment of mobile technologies for highly interactive workplaces. Initially, results of our ongoing projects in the area of mobile technologies (Niccimon) and design of virtual laboratories (VIPGEN and VIRTLAB) will be presented. In the main part of the paper we will show how these research activities can be combined towards a "pervasive laboratory" approach. A workplace concept for laboratories supported with pervasive computing technologies will be presented. Finally, we identify benefits and potentials of our approach, enabling new application scenarios for highly interactive workplaces.

2 NICCIMON MOBILE RESEARCH

2.1 *Niccimon*

Niccimon (Niccimon 2003) is the Lower Saxony Competence Center for Mobile Information Systems. It is a cooperation of three research institutes: OFFIS in Oldenburg, LfI (Information Technology Laboratory) at the University of Hanover and IfN (Institute for Communications Technology) at the Technical University of Braunschweig. With their different technological orientations, these institutes cover a large area of topics in the mobile computing field – including software engineering, geographic information systems, localization technology, speech and gesture recognition, wireless networks and mobile end user devices.

Niccimon pursues two main targets. First of all, it brings together researchers with different technological backgrounds to foster joint research and development of mobile information systems and to enable synergetic results. With their various areas of expertise, it is possible to perform challenging and highly complex research projects. Furthermore, Niccimon is the "place to go" for local industries looking for know-how and support for incorporating new technologies into their businesses.

In the next sections we will describe some results of the Niccimon project as well as some main research efforts relevant within the context of this paper.

2.2 *The mobile test platform*

Within the Niccimon project, a prototype has been developed and implemented, serving as a test platform for various mobile applications. A flexible and portable approach has been chosen to be able to adapt this platform to the different needs of various application scopes, as described below.

Another requirement was to implement the test platform in a portable way, so that it is able to run on different categories of end devices. It has first been implemented in Java on a GETAC, a "ruggedized notebook" offering the computing power of today's computers and at the same time the look and feel of a handheld device, e.g. a touch-screen and a pen as input device. The implementation (including the installation of special hardware like an electronic compass) took 5 man-years. Porting the platform to a PDA (personal digital assistant) with Personal Java took one man-month, thus proving the feasibility of the portable design.

The architecture of the platform is highly modular, the modules themselves being implemented independently from each other and client–server based. Figure 1 shows a basic outline of the developed architecture.

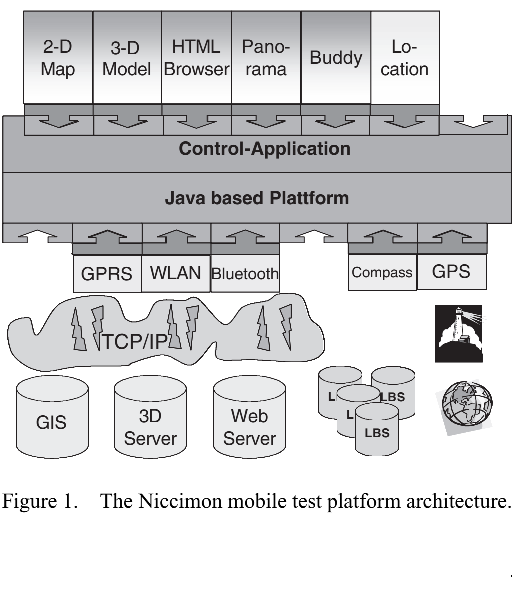

Figure 1. The Niccimon mobile test platform architecture.

The client side has been implemented in a strictly component-based framework, allowing easy extension and adaptation to different application needs. Components can easily be added or replaced, as the requirements of the applications vary. This can even be done during runtime, resulting in a "plug and play" way of using the platform.

A control application manages the communication between the components of the platform. For the communication itself, an event model has been implemented. The event model provides special events for the position information, which is widely regarded as "the important factor in mobile computing" (Baus et al. 2001, Jiang & Steenkiste 2002, Ratsimor et al. 2001), but also more general events to exchange any other kind of information. It enables the modules to share information without the need to know where the information comes from.

The implemented components can be divided into three categories: application components (e.g., 2D-Map and buddy in the upper part of Figure 1), network components (e.g., WLAN), and positioning components (GPS, compass).

Communication with the servers is handled by a network component. The communication itself is TCP/IP-based, but different transport protocols can be used by choosing different network components. WLAN, Bluetooth and GPRS have been tested so far. Every application component is connected with its application server (in case it needs one) by making use of the network component.

The buddy component enables the user to find out other people's position. A buddy list with all users of interest can be built. In this way, a user is able to keep track of and visualize the current position of a group of people.

None of the components (application, positioning or even network component) are essential. However, some components are dependent on the availability of others. For example, the 2D-Map component needs a network component to connect to the GIS server. The buddy component depends on the 2D-Map component to visualize the buddy's position.

2.3 *Indoor positioning*

So far, we have only used GPS (global positioning system) positioning for our positioning component. However, GPS does not work for indoor use. Therefore, we are investigating alternative approaches for indoor positioning. Currently, we are implementing a positioning prototype using Bluetooth beacons. The first prototypical implementation delivers a precision of 1 m, with less accuracy near walls due to signal reflections.

Another positioning method to be explored is localization by RFID-tags (Want & Russel 2000). This will allow for better accuracy. A shortcoming of this method is that the range will be much smaller compared to using Bluetooth.

2.4 *DVB-T*

DVB-T (Terrestrial Digital Video Broadcasting) is an innovative medium for wireless data transport. Primarily designed for the distribution of TV programs, it also enables high-speed data-broadcasting, individual data-exchange and new forms of information services via terrestrial networks.

As DVB-T provides a fast data downlink and can be used with mobile devices like a PDA, it enables the user to have a wireless communication connection even in areas where infrastructure supply is poor. The benefits of using digital video broadcasting technology for communication, especially at remote construction sites, have been shown in the COSMOS-project (Meissner et al. 2002). In this project a satellite-based version of DVB has been used, in order to connect mobile engineers and managers in the construction industry with the company headquarters' information systems.

Niccimon is taking part in the german launch of DVB-T in some pilot areas, which has started recently. According to the prospects of the governmental "Initiative Digital Broadcasting" (IDR), DVB-T will be a fully developed multimedia platform having replaced analogue technologies in 2010.

2.5 *Speech recognition in noisy environments*

Speech recognition as an important factor in mobile interaction (Bohnenberger et al. 2002, Kray & Porzel 2000) slowly gets into commercial use. However, there are still shortcomings in correctly processing speech input when used in noisy or disturbed environments like construction sites or inside a driving car. Niccimon is examining, within an ongoing research project, ways to improve speech recognition by filtering and methods to achieve noise reduction. In a disturbed environment, the speech processing will be done using a thin client and several powerful servers.

3 VIRTUAL LABORATORIES

3.1 *Laboratories*

Laboratories in chemistry, physics and genetic engineering constitute the workplace of many scientists and technicians performing scientific experiments. The work in such workplaces is sophisticated and requires a lot of interaction both between the workers and between workers and the laboratory devices as well. Furthermore a good insight into the theoretical background of the experiments is needed.

Practical laboratory work experience is therefore an indispensable element of training, particularly in the field of science and technology. Practical courses of this kind help users to become familiar with the handling of the equipment and also support the fundamental comprehension of the basic underlying theories.

3.2 *The VIPGEN and VIRTLAB projects*

In context of the support program "New Media in University Teaching", which was supported by the Federal Ministry of Education and Research in Germany, the project VIPGEN was initiated by OFFIS in 2001. VIPGEN represents a highly interactive virtual learning environment which provides multimedia support for genetic engineering practical courses as part of biology degree programs and is being introduced by several biology university departments (Virtual Labs 2003).

The VIPGEN system is intended to be suitable for use in all universities, allowing customization for different application scopes. The aim is to develop and introduce a software system offering extensive and complete multimedia-based support for training in genetic engineering. The application permits basic training in topics of genetic engineering in a simulated and highly interactive laboratory environment, performing genetic engineering experiments. For research purposes, scientists can develop and simulate experimental strategies of their own.

The environment of VIPGEN consists of two interconnected components: a classroom and a laboratory-room. While the classroom provides basic theory related to experiments, laboratory equipment and substances, the laboratory-room represents a living image of a real genetic laboratory. Figure 2 shows an example of a workspace in the virtual laboratory VIPGEN. Every element is rendered photo-realistically and can be operated highly interactively. Users can

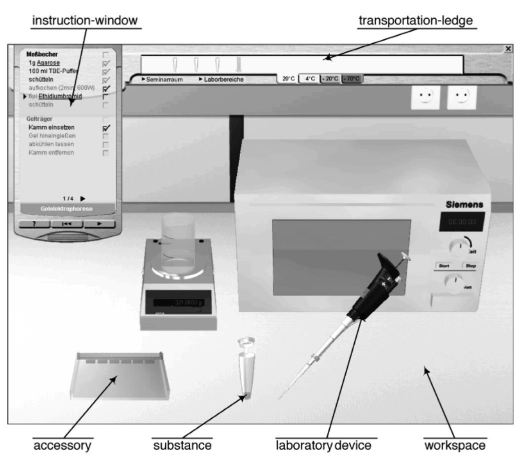

Figure 2. Example of a workspace in a virtual laboratory.

press each button on every device and are able to incorporate the experiments' sequences just like in real laboratories (Heuten & Schlattmann 2002).

Summarized, a virtual laboratory is a multimedia, simulation-based reproduction of a real laboratory into a computer system which enables explorative learning (Scherp 2002). Virtual laboratories can therefore be regarded as a special application-class of multimedia CBT systems (Bartussek et al. 1999). Unfortunately the development of such a virtual laboratory is both time-consuming and expensive. Therefore, in the VIRTLAB project, software engineering methods and tools have been investigated to improve the development process quantitatively and qualitatively, leading to more efficient and cost-effective development. The goal is to make virtual laboratories economical feasible even for very small target groups and thus more attractive for distributors.

The VIRTLAB project has been successfully terminated in December 2002. The main result of the project is a domain independent framework, which enables the development of virtual laboratories not only for genetic engineering but also for any other kind of scientific laboratories. Another result is an interactive graphical tool for defining the setup and sequence of virtual experiments. This tool is based on a derivative of the markup language XML and allows even IT-inexperienced trainers and scientists to create or adjust virtual experiments to their specific requirements. Furthermore, a software development process model with corresponding methodology, specifically orientated towards the development of virtual laboratories, has been developed (Scherp 2002). As a basis, the Rational Unified Process (RUP) was used (Kruchten 2000). The RUP was adapted and extended to the application specific use cases of virtual laboratories and their requirements.

3.3 *Towards mobile virtual laboratories*

In the future the provision and testing of PDAs or similar mobile devices with the appropriate developed services from laboratory workers will be one of our research areas. The PDAs will contain the information available in the classroom, as described in the last section. By this way each worker will always have access to the theoretical background of his/her experiments. Furthermore, experiment schedules (plots) as well as critical steps and possible errors will be presented on the PDA in an appropriate manner.

4 A PERVASIVE LABORATORY APPROACH

4.1 *General perspective*

Results and experiences from the previous described activities will be used to support our future research. The following paragraphs describe how the previous research approaches of mobile computing and design of virtual laboratories will be combined to form an innovative pervasive computing scenario for highly interactive workplaces. We identify a lot of potentials and benefits in this approach, thus making it a promising research agenda.

As previously described, work processes in scientific and technical laboratories are characterized by complex workflows and require knowledge on diverse laboratory devices and the handling of (potentially dangerous) substances. Experiments in such laboratories are usually conducted at different workspaces or rooms so that laboratory workers often need more support and guidance both when confronted with new devices or unknown experiments but also in everyday situations.

The use of mobile and wearable computing can augment and support these processes. A framework covering the whole life-cycle in laboratory work will be created in order to guide, monitor, warn, and help the employees, and will be described in the following paragraphs.

4.2 *The pervasive laboratory architecture*

Each user will be equipped with mobile or wearable devices to support him/her in his work. Sensors embedded in the laboratory devices and equipment will deliver information on their state and RFID-tags determine their position. Users will be able to get information delivered by the device sensors, to communicate with the devices as well as with other users, and to have access to manuals and knowledge concerning their work.

The appropriate identified architecture for this approach is a client–server based architecture. The proposed architecture will be the following: a server will store the data relevant for the intrinsic laboratory work, including the knowledge database for chemical substances, device manuals, experiment structure and the workflow for each single experiment. This server will be the central source of information for the laboratory workers doing their job. This server will also be the place where new experiments will be designed or existing experiments will be reconfigured, based upon the methodology developed in VIRTLAB.

The scenario strongly depends on efficient communication. Bluetooth or WLAN servers will be necessary to control and manage the communication between mobile and laboratory devices. A user and device management will keep track of all currently connected devices. Furthermore a location server will be needed to calculate the position of the laboratory workers and devices.

Planning of the experiments, including devices, substances, workflows, and scheduling will be done

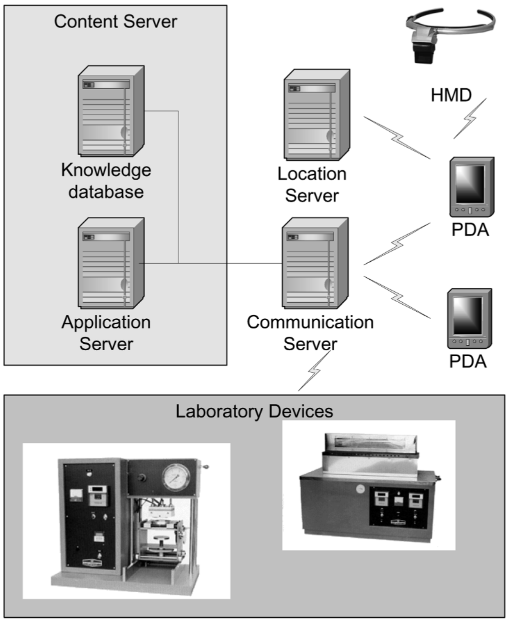

Figure 3. The pervasive laboratory architecture.

by experts on the server. Then the experiments' modules will be deployed onto the personal devices, in consideration of personal preferences, profiles, and work previously done by each individual.

4.3 *Technical details*

The central aspect of the proposed approach is to develop a framework for highly interactive workplaces. Therefore, intelligent, adaptive and self-configuring services have to be implemented. These services will be deployed onto mobile and wearable devices. They will enable systematic context sensitivity, user profiling, and personalisation.

Multimodal interaction systems will be needed to control the overall system (Kray & Porzel 2000). This should include tactile systems, speech recognition, video recording, and voice output methods. Seamless integration of technology into the usual daily work of the users is important in terms of user acceptance. The approach has to be flexible enough to allow the integration into the existing IT-infrastructure as well as extensions to meet future requirement needs.

This framework will be implemented and evaluated in a real life laboratory. Several complex tasks can be identified. The framework has to support:

- the central interoperability tasks of the multi-sensor and multi-modal computing environment,
- the deployment and integration of new devices,
- the introduction of new experiments,
- the administration of different user types (role models),
- context detection,
- adaptation to the user needs and knowledge (personalization), and
- interaction patterns.

A personal computing device like a PDA will serve as the main client device. Each user has to be equipped with a PDA. The PDA will handle the user's communication as well as the client's application logic. The general architecture of the Niccimon test platform seems appropriate to be adapted to this scenario. The new application schema can be easily included by new applications components.

Devices and equipment within the laboratory environment will be equipped with multifunctional and reconfigurable sensors and a wireless connection to the laboratory system server. Embedded systems and communication technology like Bluetooth or WLAN will therefore be used. In this way, all devices involved in the experiment will be able to continuously send their status to the server. The server application will prepare this information for access by the clients. This permits logging of the experiments as well as keeping track of the current status of the experiment.

The intelligent preparation and presentation of the available information will be of huge importance for the usability and user acceptance of the system. Therefore, for visualization purposes a head mounted display (HMD) will be used, since it enables the user to see the displayed system information and at the same time the real world remains visible in the field of view. Because of this, the worker will not be disturbed during his actions. The HMD can be connected to the PDA via Bluetooth.

Experiment workflows are an important aspect during the work. The VIRTLAB project enables the creation of a plot for a certain experiment. During the work, the user will be provided with hints, device manuals, substance characteristics, and suitable methods on how to perform the experiment on his HMD. An integrated camera connected to the HMD will be used to log the experiments' progress.

During the work, the client will continuously supervise the experiment, react to the user interactions and present all necessary information on the HMD. When problems or difficult situations occur, the client will be able to request additional information or modules via wireless network from the server, or to contact more experienced employees.

Based on the laboratory devices' status information, a maintenance and fault reporting system has to be established. The status information can be accessed wirelessly, thus enabling remote diagnostics. In emergency cases, automatic messages will be sent to the employees in charge of the experiments.

Another important aspect is the buddy component. By these means, the workers always can keep track of the position of collaborative workers or their management within the laboratory installation. This is even more important when working in potential dangerous or safety critical environments, as they may appear in environments like nuclear power plants.

Our ongoing research activities for indoor positioning will be adapted to the new scenario. The position of the workers will be determined by Bluetooth beacons. The position of less frequently moving objects like laboratory devices, equipment and perhaps even certain substances will be determined by RFID-tags attached to them. So each worker can keep track of his own position within the laboratory as well as in respect to the equipment he needs for performing his experiments.

The recording of operating data (e.g., video information from the HMD camera, logged status information of all devices, stored information about the experiment progress) will be very helpful in evaluation of experiment processes. These protocols can be used for the optimization and quality improvement of the work processes.

A sophisticated methodology has to be developed, which will help to know the used technologies and their maturity, understand change management concerning workspace and methods, secure the participation of the employees and management, and improve the quality of working conditions. As a general rule for our work, technology will always be adapted to people instead of adapting people and objectives to technology.

4.4 *Benefits*

The system described above establishes a user centered approach, which can be of benefit both for the individual employee as for the optimization of the work processes as well. Improvements can be identified in the following areas.

A lot of work in laboratories of the considered kind is safety critical. Always having access to relevant and up-to-date information will enable the employees to work less error-prone. Remote diagnostics and maintenance systems will further decrease the likeliness of possible errors. Furthermore, fault reporting and automatic alert messaging will shorten the error recovery delay time when an error occurs. Thus, a significant contribution to the safety of the workplace environment will be achieved.

Personalization of selection and presentation of the appropriate information will accommodate the users' needs and preferences. Adapting system output to the current working situation and the employees' knowledge level can provide the workers with a better understanding and orientation within the work progress. This will increase work performance and thus result in enhanced productivity of the employees.

The overall approach can significantly contribute to the increase of the efficiency of the work progress. Delay times will be less likely because of the failure handling methods and the accessibility of documentation anytime and everywhere. Improved communication facilities will also be useful in this respect. In this way, it is possible to shorten production time while simultaneously improving the quality of the resulting work.

5 CONCLUSION

Recent technology developments add value to current workspaces and can contribute to their transformation and improvement by enhancement in the productivity of work processes. Especially the potentials of mobile and pervasive computing can overcome the restrictions imposed by fixed IT infrastructures, which result in major drawbacks in certain industries still today.

In this paper, we have shown how mobile and pervasive computing can be of great benefit to highly interactive workplaces. We presented a systematical approach, especially for laboratories, as they are common in chemical industries or genetic laboratories. We have additionally stressed the benefits of our approach for the individual worker as well as for the company.

A lot of work still has to be done, and the implementation of the system will be a challenging task. However, we are convinced that the potentials of our approach and the benefits to be expected will make the efforts worthwhile.

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