An Industrial Case Study on Wearable Computing applications[1]

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ABSTRACT
Wearable computing means a paradigm shift: instead of working at the computer users are supported by computing systems in their primary tasks. Currently wearable computing is still a technology of niches and in a laboratory stage. However, with wearIT@work a project dedicated to applications was launched by the European Commission (EC IP 004216). The first 30 months of this project are over and industrial demonstrators, evaluations and results are available. In this paper we present results from industrial case studies in two of the four application domains, namely production and maintenance, with a newly designed wearable user interface.

Keywords
Wearable computing, applications, user-centred design, wearable user interface

1. INTRODUCTION
wearIT@work [1] is a European Commission-funded Integrated Project to investigate "Wearable Computing" as a technology dealing with computer systems integrated in clothing. The project has 43 partners, among them EADS, HP, Microsoft, SAP, Siemens, Skoda, Thales and Zeiss. With a project volume of 23.7 million € and a funding of 14.6 million € under contract no. 004216, *wearIT@work* is the largest project world-wide in wearable computing. In the literature the background of the project [2] and first results [3] are described.

The second phase of the cyclic development approach dealt with several technological experiments selected during this phase and with the implementation of realistic demonstrator prototypes in the application fields of the project. Each of the demonstrators is implemented according to the requirements set by the projects application partners for the respective scenario.

2. PLATFORM
The vision of Wearable Computing is motivated by the observation that today's mobile systems are not usable in situations where the user needs to focus on a task related to the real world. Thus the most general definition of a wearable computer is a functional definition of a system that can be used at any time and anywhere and does not in any way disturb the user's interaction with the real world. It is generally agreed that the key properties required to achieve the above are (1) non- disruptive user interfaces characterised by a low cognitive load, (2) hands-free operation, (3) an unobtrusive form factor, (4) the ability to model, recognise and act upon events in the environment (context sensitivity), and (4) seamless, ubiquitous connectivity. On a certain high level the above requirements are fairly obvious. From the application point of view it is equally obvious that today no system really fulfils them. What is less obvious is how the above functional definition should translate into a technical specification and how the development towards fulfilling such specification should best proceed in the near future. In the technical and scientific community there is a heated debate about what constitutes a wearable system with visions ranging from building on commercially available 'PC on a belt' and PDA solutions to integrate concepts of transistor level integration of electronics into textile fibres.

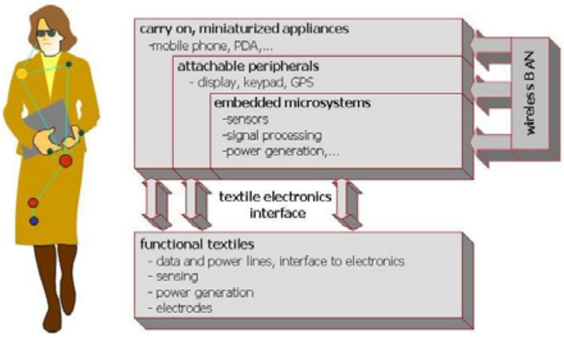

Figure 1. Open Wearable Computing Platform.

Although the application domains and their requirements vary quite a lot the project aims to have a common hardware platform

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and software framework to allow for standardization and a unified approach for application development. Figure 1 shows wearIT@work's answer to the above questions summarising user requirements gained during the first two years, when the four layer Open Wearable Computing Hardware Platform (OWCP) was developed.

An overview on the Open Wearable Computing Framework - OWCF is given in Figure 2. As a software infrastructure it supports the construction of domain specific applications for wearable devices. It is a tool used by all *wearIT@work* demonstrators. During the conceptualisation phase guidelines have been set up to simplify the software development process, to encourage reuse of software components across different applications, and to promote better software engineering practices.

The definition of the framework requirements took place based on a continuous analysis of end-user requirements.

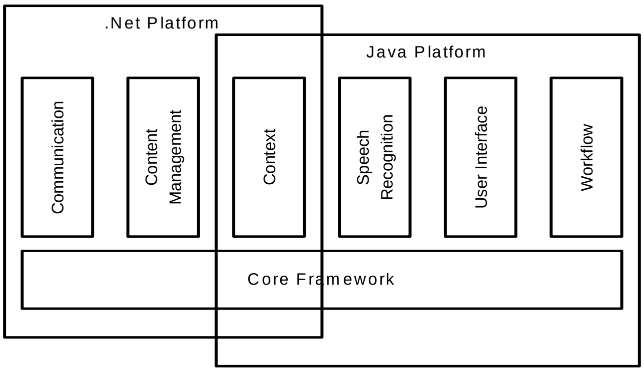

Figure 2: Overview on OWCF components

The spring framework[2] was selected as the core of the OWCF to minimise demand on resources, because of its minimal invasive effect on components, and the related inversion of the control design pattern. It allows for configuration not only of configuration parameters but for the configuration of dependencies among components, too. Currently parts of the Framework are available as a .Net implementation in MS-Windows environments, other parts as a Java implementation for Linux platforms.

After design, development, test, and release of the framework components training and support of pilot application developers was performed.

The modules implemented support security and safety requirements found analysing the pilot scenarios. Security and safety requirements could be solved by state-of-the-art security technology identification implementing available off-the-shelf technologies.

Several lessons have been learnt during the development of the framework:

- The OWCF requirements must be extrapolated from the end-user requirements;
- Training and support of pilot application developers by the developers of the framework is unavoidable;
- One of the challenges is testing the framework. Sample applications must be built, and contexts, content and inputs by the demonstrators must be simulated;
- Applications should maintain a clear separation between content, presentation, and logic

The Open Wearable Computing Framework is ready for take-up by interested parties. It is contained in the wearIT@work software repository[3]. It is foreseen to have an implementation of all modules on both platforms at the end of the project (late 2008).

3. APPLICATIONS

In **automobile assembly** the final assembly steps are still manual. The application partner of the project is the car manufacturer Skoda in the Czech Republic. These final assembly tasks are complex. Therefore all Skoda workers receive training at the so called Learning Factory, part of the Skoda factory in Vraclabi. Theoretical training at the 'e-Learning Institute' and practical training at the 'Learning Island' is performed. Approximately 5 to 6 hours training of the worker is today required for this task by an experienced trainer. The goal is to support the training at the Learning Island by further integrating the theoretical training into the practical training and at the end integrated at the assembly line directly.

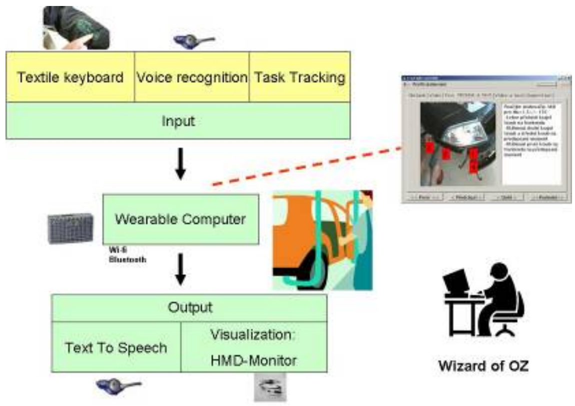

Figure 3: User-oriented production demonstrator

Two demonstrators supporting training on the final assembly of the front light of a Skoda Octavia (see Figure 33) were developed, evaluated, refined and integrated to a unique demonstrator after the first of four innovation cycles of the project. One demonstrator was focusing on usability aspects of the solution like the use of textile keyboards and speech input. The second was focusing on automatic task recognition using a sensor network [4] performing event-based activity tracking experiments to achieve automatic context detection [5]. A result of these studies was that both solutions could be integrated enhancing also the stability of the technological solutions selected to automatically detect the task sequence and the resulting contexts during manual assembly tasks. Evaluating the user acceptance a

[2] See http://www.springframework.org/ accessed 25.10.2006.

[3] See https://wiaw-file.informatik.uni-bremen.de/svn/wiaw accessed 25.10.2006; contact the authors for user access.

re-definition of the scenarios became necessary to make the prototype usable for the production line.

The results of the experiments with these two demonstrators were the basis for the design of a second generation unified demonstrator. In particular the wizard of Oz based experiments were further developed integrating wearable computing platform components for the wearable user interface and the context detection. The task recognition system was improved by reducing the number of sensors necessary. Nevertheless some sensors built into the car body are still necessary.

To evaluate the productivity of the wearable computing solution usability experiments have been performed comparing different input and output devices like monocular look through and look-around displays, binocular head mounted displays, a wall mounted screen and paper. The task performance and the learning productivity were evaluated in a setting dealing with the assembly of mechanical parts and some cable connection in a 3D assembly environment. Experiments with 46 assembly workers have shown that in the test environment assembly instruction by paper being the faster, less erroneous and the easier to learn instruction method compared to the use of a wearable computer. However, when instructing the user with context information similar productivity could be achieved compared to using paper based instructions. The use of keyboards and voice information compared to the wearable computing solution produced worse results. Additionally in the case of context support the learning effect is comparable to the paper based approach [6]. What's more the possibility of implicit documentation, enhanced quality and documentation of the assembly process with a minimum of additional effort was seen as an advantage of the wearable technology. The results of these usability studies became part of the enhanced wearable computing solution with improved human computer interfaces. It is based on the framework using the context detection and wearable user interface modules for gesture and speech interaction with increased robustness [7].

The same wearable user interface module was used in the following **aircraft maintenance** application and will be described here in more detail. The work of aircraft maintenance personnel has to be done inside and outside of airplanes. Planning to use wearable information technology in such an environment needs the consideration of several limitations like constrained spaces and the related motion restrictions, uncomfortable working positions, water, heat, and corrosive products in the environment and so on. Issues like security, safety, and confidentiality rules have to be taken into account when maintaining an airplane.

Extensive user studies with design workshops, tests and interviews with the different stakeholders covering technological, economical, social and ethical aspects have been performed at Aircraft Maintenance Service Centres in France and Germany to ensure the wearable system applied for the maintenance demonstrator meets the needs of the workers.

Based on these experiences experiments with different user interfaces were done in a set-up as shown in figure 4. In this set-up the input by a track-ball finger mouse was compared with input using a data glove and speech input. As feedback to the voice and different visual output modalities like text, drawings, photographs and videos were tested and evaluated. The tests and interviews have been performed with a group of 30 people. The group consisted of male and female German maintenance personnel, technical and non technical persons with an academic background of different age and working experience.

The experiments have shown voice input being the most ineffective method when initiating a command. Input by a trackball was a little more effective as input by the data glove. It has to be considered the trackball being a well known input device, but does not allow hands-free operation. Voice input was in so far problematic as the instructions are in English and the German accent created problems. Exceptions were female candidates with a higher language education. Less computer experience was also an advantage when using the glove.

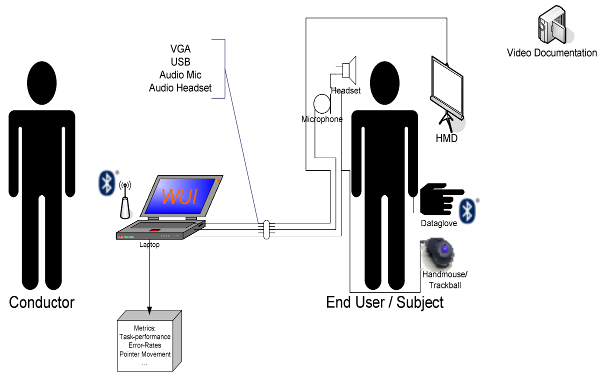

Figure 4: Set up of aircraft maintenance usability

Figure 5: Wearable computing hardware

In a second trial - using the findings of the previous experiments - a wearable computing solution was developed with a special vest and an OQO connected to a Microoptical SP6 display (figure 5). The OQO was connected by a Bluetooth interface to a refined version of the glove with an RFID reader for identification purposes.

As an application the removal of seats in the aircraft was chosen. - There exists a great many of diverse kinds of seats with different fixtures requiring special purpose tools for removal. The specific information is supplied by the RFID tag on the individual seat and displayed depending on the expertise of the user.

Figure 6 shows the sequence of operations to be performed when removing a seat from its fixture in an airplane.

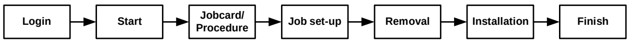

Figure 6: Seat removal operation sequence

The operator is guided through each step of this procedure by the wearable device shown in figure 7. The wearable device supplies the operator with guided, context-controlled access to the aircraft maintenance manual (see figure 8), with hints about steps to be performed and with more extensive advice, if necessary.

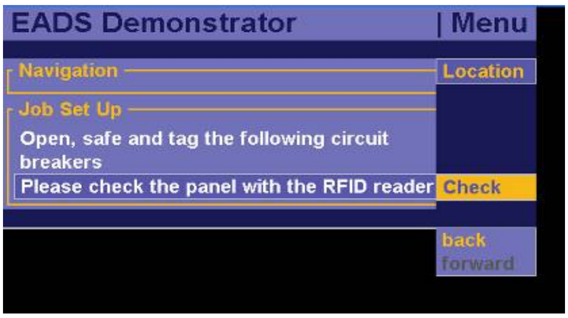

Figure 7: Head mounted device operations menu

There has been a positive reaction by the maintenance personnel accepting there is a more efficient and easier workflow. During the interviews workers expressed their concern about becoming overly dependent on the wearable. They recommended a back up of printed manuals and checklists, and the periodical re-training of in-depth procedures. Collaboration by wearables could improve efficiency and autonomy as well. Face to face communication would still be necessary. Physical interactions and contact should be retained and promoted. Operators emphasized the need for training and support when the system is introduced.

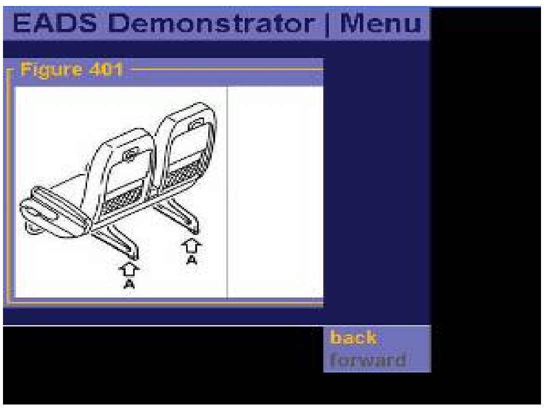

Figure 8: Wearable operator manual

To avoid disabled, e.g., hearing impaired workers to be limited to use wearables, disabilities should be considered already in the design phase. It was also stated that wearables can enhance the professional work and the identity of the users. This should be emphasized during design and implementation [8].

4. CONCLUSION

In this paper we present results from two industrial case studies in automotive production and aircraft maintenance. In a cyclic user-centred design approach within two innovation cycles usability tests and technology tests were performed. The hardware and software development process required some standardisation as it was achieved with the Open Wearable Computing Platform and the Open Wearable Computing Framework. Especially for the wearable user interface and the context detection a standard solution was found, could be applied and evaluated in two different working environments with different cultural backgrounds. To have separate tests for the usability and the technology is one of our lessons learned. Voice recognition requires special skills of the end users which must be trained and cannot be assumed as given in a blue collar environment when the working language is not the native one. Furthermore the involvement of really all stakeholders is required to end up with solutions ready for use in the real industrial environment.

5. ACKNOWLEDGMENT

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