A Wearable Computing Prototype for supporting training activities in Automotive Production

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Abstract. This paper presents the results of the wearable computing prototype supporting training- and qualification activities at the SKODA production facilities in Czech Republic. The emerged prototype is based upon the first of the 2 main "Variant Production Showcases" (training and assembly-line) which are to be implemented in the WearIT@work project (EC IP 004216). As an introduction, the authors of this paper investigate current training processes at Skoda, and derive the potential benefits and risks of applying wearable computing technology. Accordingly, the approach of creating the wearable prototypes, via usability experiments at the Skoda production site, is explained in detail. As a preliminary result, the first functional prototypes, including a task recognition prototype, based upon the components of the European Wearable Computing Platform, are described. The paper is rounded up by providing a short outlook regarding the second envisaged test case, which is focussed upon selected assembly line operations of blue collar workers.

Keywords: wearable computing, automotive production, training, usability, task recognition

1 Introduction

Since the late 90's, applying Wearable Computing in industrial work environments has become an attractive approach to efficiently support mobile work processes [Siew96]. Automotive production inhibits an industrial environment where variant products of high complexity and short life-cycles are manufactured [Kir06]. Hence, many situations exist where work is performed in a mobile manner (e.g. maintenance, work at the assembly line, etc.). In order to cope with these conditions, concerted training of personnel is a very crucial issue in automotive production. Accordingly, training requirements are usually high. The European research project WearIT@work investigates, amongst other scenarios, the impact of wearable computing in automotive production. Since the beginning of 2004, a thorough analysis was carried out, involving interviews, field studies and comprehensive process analysis at the Skoda production facilities in *Mlada Boleslav* and *Vrchlabi* (Czech Republic). The aim was to implement a wearable computing solution which is capable of supporting the training procedures of Skoda blue collar assembly line workers. The wearable prototype which derived from these field-studies, offers semi-autonomous training by mobile- and context-sensitive support of trainee personnel. The trainees are provided with all necessary (digital) information in order to successfully perform individual production tasks. At the same time the performed tasks are tracked via mobile sensors mounted on a data glove and a car body. Particularly, the wearable system supports the trainees by detecting errors when tasks were not performed correctly, and by providing appropriate help and suggestions [Ma06]. The trainee can interact with the system through voice, and head-mounted display (HMD). What is even more important is that he/she does not need to interact at all, because the system recognizes the tasks performed and presents the information automatically.

2 The Training Process at Skoda

The two Skoda production facilities involved in the variant production showcase are signed by the fact that the personnel must receive theoretical and practical training before they are authorized to work at the assembly line.

The current training process is carried out at the so-called “E-factory” in Vrchlabi, and comprises two separate phases:

- Theoretical training is provided at the E-Learning Institute of Skoda using didactic material (Fig. 1) created by the Skoda training department, combining text, images and videos. The material is provided in paper- or in electronic format. The students must pass various tests before going on to the practical stage.
- The Learning Island. Using a real vehicle chassis, the students are required to put the theory into practice under the observation of a supervisor. The supervisor evaluates the individual actions of the trainee, while pointing out errors and providing suggestions for improvement. At the end the supervisor decides whether the trainees are ready to start working at the assembly line.

Fig. 2 illustrates how training is currently performed under the presence of the supervisor. Thus, a fully autonomous learning, without the presence of a supervisor, is not yet practiced at Skoda.

Fig. 1: Didactic Material used during the Skoda training procedure.


Fig. 2: Demonstration of the installation of the front headlights by the supervisor.

2.1 Training with Wearable Computing – Benefits and Risks

Compared to stationary computer systems, mobile- and wearable computing technology have seriously caught up in performance, functionality, scalability. This makes training solutions based on mobile- and wearable computing an attractive consideration for industrial organisations. In this sense, one of the objectives of WearIT@work was to supplement the training procedures at Skoda with a context-sensitive wearable computing solution. The idea was that the trainees gain mobile access to the information (e.g. instructions and required tools) to carry out their assembly tasks. In fact, the wearable system was used to recognize the context of performed work, and as a result provide the trainee with the required information to adequately perform individual assembly tasks. Concurrently the wearable computing system tracks the trainees' activities and analyses them. While the workers perform their training, the supervisor is connected to all active wearable systems via his PC, and can monitor all activities. The nature of the assembly activity itself made it necessary to design a system that does not restrict workers' freedom of movement, while allowing them to handle all necessary components and tools. It was especially crucial to take into account that workers had to adopt many different postures during the assembly process: crouching, standing, seated, inside- and outside of the car. It can be assumed that one of the main advantages of a wearable training solution is that the constant direct presence of the supervisor is no longer required. Thus, the supervisor has the opportunity to observe a number of trainees at the same time via his PC. Since the supervisor has a continuous overview of real-time information such as performed activity, number of mistakes, and number of repetitions, he may interact with the trainees in difficult situations. Eventually, an immediate benefit of using wearable solutions in automotive production is that the time of training procedures may be reduced. On the other hand this only applies when the threshold for getting acquainted with the wearable system is low enough. In order to ensure this, the wearable prototype is designed in line with the real requirements of the user (user-centred design). Additionally the chosen setup does not introduce much additional effort on the user, because accessing required information is done without or only with minimized explicit interaction with the system. In this manner there is no need for the user to be distracted e.g. by a stationary interaction device, such as keyboard or mouse that would impair the way the trainees do their job.

3 Initial Work

3.1 Usability Experiments at Vrchlabi

In the first phase of the project the aim was to create a wearable system that supported the training process in the learning island. This first prototype formed the basis to evaluate the different modalities of interaction with the assembly line workers under real conditions in the SKODA production site at Vrchlabi, Czech Republic. These were voice recognition, textile keyboard, non-explicit- or task recognition-based interaction, and Head Mounted Displays. The front headlight assembly process was selected as a test case since this specific process represents a complex enough task which justifies the use of wearable technologies during training. An additional aim was to acquire the users' feedback, regarding their preferences and attitudes towards several hardware-, software-, user interface- and remote support-related-features. Finally, the results obtained had to be useful for future analysis on the impact of wearable technologies in the training process itself. The detailed evaluation procedure has been described comprehensively in [Mau06].

The findings of the experiments were manifold. Generally, the usability test with the real end-users was rather complicated, as they had to be picked out from the running assembly line. Therefore the time schedule for usability testing was very tight, making it impossible to extend the tests when required. On the other hand it was not possible to recruit the amount of users needed in order to obtain statistically significant results. Dealing with real end-users, it was not feasible, trying to apply a user-centred approach through a human translator. In fact, all end users were unable to understand and speak English, which required the services of a professional Czech/English translator. These constraints prevented the usage of some effective techniques like ‘thinking aloud’, thus, interaction with the workers turned out to be un-natural and difficult. Additionally, it had to be dealt with the fact that the design-/developing team consisted of remotely located partners, what made it very complicated to guarantee a real iterative design process. Apart from these aspects, it was difficult to measure system performance. As a result it was not easy to quantitatively evaluate the training process. Due to the “learning effects”, it was not legitimate to use the same worker to measure the same training process before and after the introduction of wearable technology. Furthermore it was difficult to compare two different users because of their different skills and learning capabilities. Nevertheless, the first results of the experiment confirmed that the wearable system was well accepted. Regarding all theoretical concerns about lack of privacy and loss in autonomy, it was a surprise that one of the favourite features of the workers was the ability of the wearable system to monitor the task completeness. In fact, when one of the workers made a mistake in the assembling process, the system detected it, and triggered an error message. Later on, during the post-questionnaire, it was one of the most valuables features the worker identified. It was also observed that one of the workers was very uncomfortable wearing the HMDs. This particular worker preferred using a large display in order to view the information. It has to be underlined as well, that video support was not requested by the majority of the workers. Generally they preferred pictures with aggregated information in comparison to simple text.

The main outcome of the Vrchlabi Usability Experiments was the decision to perform new usability experiments in Spain. The purpose was to involve a larger group of end-users located near the research team in order to overcome the constraints experienced at Skoda.

3.2 Usability Experiments at Tekniker

In order that the experiments were successful, an infrastructure was set-up to carry out assembly tasks. The prerequisites for such an infrastructure were rather simple:

- It should allow creating as many different tasks as we need,
- All tasks had to be of a similar complexity degree,
- The assembly task should involve the use of manually- or tool assisted part manipulation

Two main experiments on usability have been carried out using this platform. The aim of the first experiment was to extend the initial findings of the experiment made with the workers of Skoda at Vrchlabi. The intention was to measure the acceptance of the system. Besides, the performance in terms of memorability (how fast workers get trained), and in terms of task completion (time consumed and errors made). All in all 40 workers took part in the experiment.

In summary the main findings were:

- Users improved their performance when using the wearable system with implicit interaction: The assembly tasks were performed faster and with less error. In fact, it took 67 seconds less in average than when paper-based information was used which was actually the second best alternative.
- Users did not learn faster using a wearable system. In fact, people were able to learn faster through paper-based support. Although the difference was neglectable when compared to those using context based interaction.
- In the test performed the day after, paper-based learning performed the best, while context-based interaction performed the worst.
- Voice recognition-based interaction was the preferred interaction modality by workers.
- Workers preferred graphical information to text.
- Workers found the system very useful when doing a complex task, allowing hands free access to information, avoiding dispensable movements in order to check information

The second experiment was aimed to compare the benefits of using Head Mounted Displays (HMDs) to access information, versus the presentation of the same information on a large screen near the working place. 20 workers took part in the experiment and 3 different HMD evaluated..

The best performance was obtained when the information was presented on the large display, and the worst when accessing through the binocular HMD. However, when asked about the user's preferences, most of users chose the binocular HMD as the best choice.

3.3 The task recognition Prototype

In order to track the progress of the headlight assembly, sensors were integrated on distinctive parts of the car body, on the worker, and also on the tools. This was done to guarantee a detection of sub-tasks which are relevant for the different steps in the workflow.

As on-body sensor, a RFID reader has been attached on the back of the user's hand. With the information coming from this reader, required tools such as two cordless screwdrivers can be detected and uniquely identified. In addition, an inertial sensor package has been placed on the back of the user's hand. This module provides a three-axis accelerometer and gyroscope. It is used to pick up the incidence of the torque limiter of the cordless screwdrivers, which occurs when a screw is properly tightened according to the chosen torque.

As wiring up the worker would be too great an impediment for the user during his work, all data streams from the wearable sensors are transmitted using Bluetooth modules.

The correct positioning of the assembled car components is monitored by a set of stationary sensors mounted directly on the car body. Critical locations with permanent contact to the component, e.g. the contact surfaces behind screws, are monitored by measuring the force exerted on force sensitive resistors (FSR) on these surfaces. The FSRs' very low thickness (about 0.5 mm) allows them to be placed on such positions without modifications of the components or the car body. At locations where the assembled components do not touch the car body, we used magnetically triggered reed switches. They also measure the proximity of alignment checking tools used at specific places for quality control.

The current setup uses 5 FSR sensors and 4 reed switches around screw positions, the back of the lamp body, and the checkpoints for the alignment tools. The signals from stationary sensors are read and preprocessed by a microcontroller based data acquisition module, which is mounted inside the engine compartment.

The data streams coming from the wearable sensors on the user and the stationary sensors inside the car body are gathered and further processed by the Context Recognition Toolbox (CRN) [Ba06]. This software framework provides a library of data processing algorithm modules frequently used for context recognition, and allows to set up a process network using these modules. Fig. 3 illustrates the detailed network, which has been used for the task recognition prototype. The left part comprises the processing of FSRs and reed switches. After some signal conditioning, a threshold operator is applied to detect the status of the respective sensor. The middle thread in figure 1 shows the CRN tasks, which are dealing with the RFID reader. On the right side, the chain of tasks is depicted which detects the occurrence of the described torque limiter. A more detailed description of the data processing and the resulting event creation is given in [St05]. A merger task brings these three streams together and sends it to the JContextAPI using a TCP/IP connection.

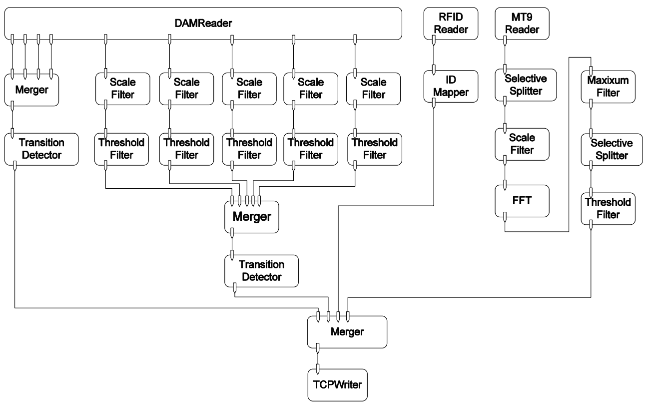

Fig. 3: Detailed Network used for the Task recognition Prototype

4. The final Prototype

4.1 Hardware Architecture

The current prototype is based on a distributed architecture using several components from the Wearit@work framework. The main device is an OQO Model

01+ [Oq01], which the user wears attached to his belt. The OQO technical characteristics offer enough computational power to fully support the application, and it also allows for appropriate connectivity: network, bluetooth, external VGA output. The user has a Carl Zeiss binocular look-around head mounted display [Ze01], and a Sony Ericson HBH-300 bluetooth headset to interact with the prototype application via voice commands.

The tracking of the user's actions is enabled by a special data glove that has been engineered by ETH Zurich. It comprises an inertial sensor package for motion detection and a RFID reader to identify utilized tools. In addition, a set of force resistive sensors and magnetic switches is attached to the car body for monitoring interactions between tools, assembly parts and the car body itself. The output of the sensors is collected by a stationary system (a laptop), which processes them and makes them available for the recognition of user's actions. Fig. 4 shows a user wearing the wearable hardware components.

Fig. 4: User wearing the hardware components

4.2 Software Architecture

The software architecture is shown in Fig. 5. The end-user application (henceforth also referred to as application, for brevity) is written in Java and it runs on the OQO. Further, it relies on the Open Wearable Computing Framework (OWCF), which has been developed within the Wearit@work project. Specifically, the application uses the following OWCF components: Wearable User Interface (WUI) and JContextAPI (JContextAPI is an implementation and an extension of the ideas presented in [Sb06]).

The application shown in Fig. 6 is modelled internally as a finite state machine: each state corresponds to a specific task of the assembly procedure for which the user is being trained; transitions are triggered by user actions, both explicit (for example voice commands) and implicit (i.e. actions that are performed as part of the assembly procedure, and that are detected and recognized automatically by the system). The application is capable of tracking the sequence of user's actions, and to monitor that such sequence corresponds to what is expected in the assembly procedure. Whenever the user performs an unexpected action, the application displays a warning message, and can contextually provide appropriate help to support the user.

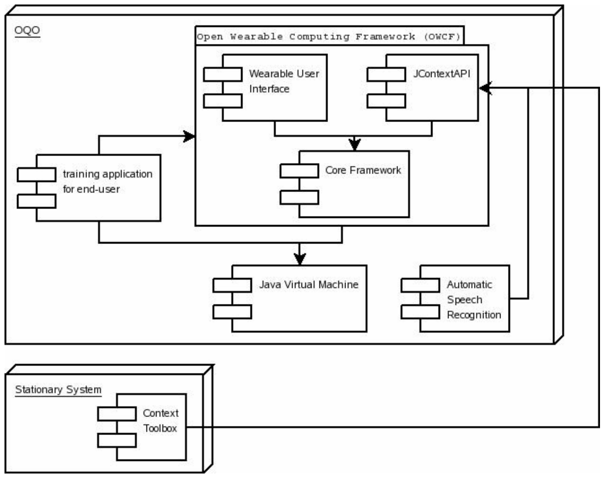

Fig. 5: Software Architecture

The application user interface is based on the WUI [Wi07,Wi06], which presents the required information to support the user during the steps of the assembly procedure in the most suitable way. The WUI is engineered to obtain the best result in presenting the output on “look around” head mounted displays. Further, it provides a very good support for the state-based architecture of the application. As such, states can be associated with abstract screen structures, each of which are rendered as the required graphical widgets (text boxes, pictures, menu items, etc.), and the navigation towards other screens. The WUI also takes care of building the best rendering of the user interface dependent upon the output device. For this, the envisioned interface capabilities are described with an abstract model independent of any specific interaction style or output medium; implementing a ‘separation of concerns software’ approach. Hence, application developers can focus on specifying required in- and output behaviour of the envisioned interface, without being in need to take care of its resulting rendering.

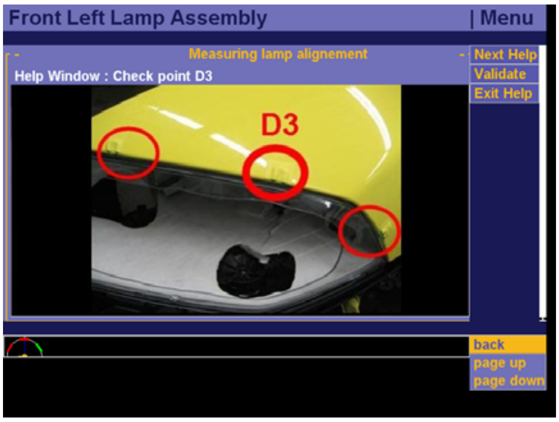

Fig. 6: The user-oriented application

Transitions of the application state machine are provided by JContextAPI in the form of events: The application simply registers listeners for the relevant events, and JContextAPI notifies the registered listeners whenever those events happen within the system. There are two major event sources in the current software architecture: the Context Toolbox [Ba06], which is running on the Stationary System, and the Automatic Speech Recognition (ASR) component, which is also running on the OQO. The *Context Toolbox* is used to process the signals coming from the special data glove worn by the user, and from the sensors attached to the car body. Such data are transferred to the OQO via TCP socket, and are processed by JContextAPI, which transform them in events, and eventually notifies registered listeners. The same approach is used with the *Automatic Speech Recognition (ASR)* component. The current version of the prototype uses a commercial ASR, Dragon Naturally Speaking from Scansoft [Sc01]. The ASR is trained to recognize some specific commands (words like "show help", "next", etc.), and publishes the recognized token on a TCP socket. JContextAPI transforms this data into events that are forwarded to registered listeners.

Notice that JContextAPI performs also some additional elaboration of the data received by the Context Toolbox, in order to generate events of a higher abstraction level. This feature is useful and meaningful to the application, and can be used to trigger transitions in its internal finite state machine.

The usage of the OWCF components has simplified the engineering of the application providing several benefits:

- the WUI supports the rendering of a simple user interface structure specifically targeting head mounted displays
- the JContextAPI enables context awareness through the simple and straightforward mechanism of event subscription/notification.

In general OWCF has provided a set of reusable components that shielded the application developers from the complexities related to the interfacing and handling of lower level system resources and data sources.

5. Conclusions and Further Work

The results of the study have confirmed that effective training of personnel in automotive production is one of the most crucial factors which are responsible for securing production flexibility. The developed wearable computing prototype enables a context-sensitive provision of necessary information to the training personnel. The wearable solution was able to track and analyse the trainee's actions, while providing the end user with actions for error handling. As a result, semi-autonomous training of trainees in automotive production was realised.

In the usage of wearable computing solutions for supporting training procedures, high benefits can be expected. However, at current stage there is not yet enough experimental data to draw clear conclusions on further benefits and issues of the proposed solution. Nevertheless the consortium will continue to refine the solution according to end-users feedback, and to conduct further tests and field studies within Skoda in order to gather enough knowledge to evaluate the prototype more comprehensively. In this respect there are some interesting features that have to be tested before the final prototype can be deployed in the E-Learning Institute, in 2007:

- There is a new wristband designed and developed that has to be tested, both in terms of performance and -user acceptance,
- Collaboration between trainer and trainee has to be implemented,
- Different methods for event notification have to be tested.

Besides the refinement of the final training prototype, WearIt@work envisages a second wearable prototype which will empower blue collar workers in selected stations of the assembly -line. In this context an extensive field study was recently initiated, and will continue until the second quarter of 2007. The studies will include an end user- and process study, which shall directly impact the features of the second prototype According to the most recent requirements analysis with the Skoda end users, WearIT@work has identified the quality assurance operations at the assembly-line as a promising test scenario for employing wearable computing. Regarding this particular scenario, blue collar workers manually and visually check the functionalities of specific features of the almost finished car (e.g. doors, windows, and trunk). It is the aim of the workers to find errors and malfunctions which are then to be documented (for the time being: paper-based). Thus, the total number of errors is to be reduced before the car is audited in its final station (namely before being shipped to the customer). The objective of the scenario shall be to empower the workers with wearable computing, in order that they may be supported in error detection and –documentation. As such, we believe that as an outcome, a substantial reduction of total errors can be achieved. For the technical realisation of the wearable solution, components (hardware as well as software) developed for the training scenario will be reused and adapted to the specific requirements of the end users. Additionally, we will make use of synergies existing among other WearIT@work scenarios such as inspection procedures for aircraft maintenance.

Regarding the application of the User Centred Design approach, it came out that within an international integrated project, guaranteeing this kind of approach is not at all an easy task. In fact, the cultural and geographical distance makes it quite difficult to apply an orthodox approach. In WearIT@work, the production pilot team is following their own sophisticated methodology: namely an initial requirement elicitation process with real end-users, usability tests with local users close to the research team, and final validation with final end users. It must however be mentioned that it is nevertheless very difficult to get hold of the real end users in a global company where production is highly dependent upon human resources. Moreover, a critical selection of the 'right' end users is crucial due to diverse cultural- and educational backgrounds. Conclusively not any end user, e.g. of the assembly-line, is suitable for interviewing and evaluation purposes. WearITwork is currently in the middle of this process, and is planning to have preliminary results in early 2007, which will naturally be subject to publishment.

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