Wearable Computers and Wearable Electronics: The Last Mile to Ubiquitous Computing

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Abstract

Wearable computers and wearable electronics constitute the interface between humans and their surrounding ubiquitous computing environment. By wearing IT technology, we gain direct and consistent access to information and communication networks without having to utilize additional devices. This article will discuss definitions and application scenarios of wearable computers and wearable electronics, showing meaningful examples of different device and application classes. Furthermore, the author describes the necessary technology to introduce such systems and gives a prediction on usage scenarios of upcoming applications for wearable technology.

1. Introduction

Wearable computers and wearable electronics are increasingly becoming usable, fashionable and thus marketable. While wearable computers are miniaturized personal computers that can be worn on a belt or carried in a pocket, we see wearable electronics rather as clothing or accessories that become intelligent through embedded IT functionality, such as processing power or sensing capabilities. Both are close to the human body, and that way "wearables" represent the "last mile" between the surrounding ubiquitous IT infrastructure and the user. By using wearable technology and wireless communication, such as WLAN, Bluetooth or 3G, we can provide instant access to necessary information, either via the company network or via public information or entertainment portals [1].

Ubiquitous computing, as defined by its inventor Mark Weiser, suggests that "the PC and workstation will wither because computing access will be everywhere: in the walls, on wrists, and in 'scrap computers' (like scrap paper) lying about to be grabbed as needed" [2]. While this ubiquitous computing environment is already around us in some form or another, we still need interfaces to access such an environment. Handheld devices sufficiently fulfill this function but still have to be "grabbed when needed" and block at least one hand. Wearables fill this gap and can push forward the ubiquitous computing idea and thus become the last mile between humans and surrounding IT environments.

The following sections illustrate wearable technology and related research challenges, application scenarios and give an outlook on the developments of wearable computers and wearable electronics.

2. Wearable technology

Wearing objects instead of carrying them has one main advantage: the hands stay free for other functions, being it work tasks or recreational activities. The term "wearable" in the context of wearable computers and wearable electronics comprises various definitions of taking IT technology along. While some definitions are stricter and thus demand the technology to be an "integral part of our every day outfit" [3], others will allow for any possibility to attach a piece of computing hardware to the human body [4].

The development of wearables derives from two directions: computers, which are compact and light and have the same performance level as laptop computers; and smaller devices, emerging from smart textiles that include computing power into clothing, fabrics or accessories, such as jewelry. While we will see a broad range of solutions in-between these two ideas, we have two paradigms today: wearable computers and wearable electronics.

2.1. Wearable computers

A wearable computer is a body-worn IT device that offers hands-free operation, e.g. through speech control. With a head- or body-mounted display it can provide access to data without blocking the field of view of the user. Thus, wearable computers can support work processes without interrupting the workflow itself.

Wearable computers to date support rather high-end blue-collar activities that require access to IT infrastructure without permanently blocking the hands of the user. Key features of such systems are head-worn displays that bring the computer screen directly in front of the eye of the user, and speech recognition, which enables hands-free interaction with the computer (see Figure 1).

Figure 1 Xybernaut® MA® V; IBM prototype; Vocollect Talkman® (left to right)

Caused by these demands on the hardware, wearable computers are derived from laptop / desktop computers and offer similar functionality. Since the miniaturization is foreseeable, we can predict these wearables to end up in PDA- or phone-sized devices that provide enough processing power and data storage volume to function as effective tools for mobile workers. Combined with wireless network connection, they will eventually merge into single communication, documentation and knowledge base devices.

In contrast to these miniaturized computers that were shrunk from big to small, there is another class of wearables, which are rather 'intelligentized' clothes and accessories and provide embedded IT functionality that emerge from integrated products to usable, unobtrusive day-to-day assistants: wearable electronics (see Figure 2).

2.2. Wearable electronics

Infineon defined wearable electronics as: "Highly-integrated chips with extremely low power consumption [which] are directly sewn or woven into textile fabrics, thus allowing the full integration of electronic applications in clothes" [5].

Figure 2 Infineon / O'Neill MP3 jacket (left); Motorola Bluetooth-enabled accessories

Wearable electronics tend to be less obtrusive and less noticeable as their bigger counterparts. They comprise a broad functionality ranging from intelligent fabrics that contain consumer products, such as music players, mobile phones or appropriate connection interfaces, to sensing devices that monitor the health or environment of the user (the wearer). Although wearable electronics seem to rather target the white-collar and even more the consumer market, this technology will as well merge towards - i.e. offer the functionality of - PDAs and mobile phones, and thus complete the wearable technology range.

3. Research challenges

Making wearable technology truly usable involves a number of research challenges that have to be addressed [6].

3.1. Processing power

Depending on the function, the single wearable components need to offer the appropriate processing power; e.g. high level CPU for speech recognition, low processing power for sensing devices and thin client components. The challenge for the right processing power lies in the trade-off between performance and power demands.

3.2. Power supply

The kind and amount of power supply depends on the required processing power and the application scenario, i.e. it depends on the usage intervals and durations of each component, and on the accessibility of the power source [7].

3.3. Wireless connectivity

Wireless connectivity is important in regard to two aspects: a) communication amongst different wearable components, such as wireless input and output interfaces or storage devices, e.g. via RF or Bluetooth [8]; and b) communication with surrounding IT infrastructure, providing access to external data and information via GSM, 3G, WLAN and other radio communication [9].

3.4. Miniaturization

Miniaturization for wearable computers mostly involves the challenges illustrated in the previous sections. For example, the housing size of the computer depends on the battery size, the heat dissipation from the processing unit and modules that provide additional functionality or connectivity to the outside. Really miniaturized and unobtrusive are wearables, which are included in smart textiles [10] or included into accessories, such as jewelry [11] or sun shades [12].

3.5. Software / hardware architectures

To allow for a connection with stationary IT systems the appropriate software systems that support those wearable devices have to be developed [13]; furthermore, standardized user interfaces, especially with respect to hands-free interaction with these devices have to be set in place [14].

3.6. Application software

The application scenarios for use of wearable computers and wearable electronics require appropriate application software and a sound software development process, in regard to the specific challenges of wearable technology. The next section will discuss this issue and will give real-world user feedback.

4. Application scenarios

Application scenarios for wearable computers and wearable electronics are manifold. In the area of wearable computing, several projects have been conducted in research groups at institutions, such as MIT, Carnegie Mellon and Georgia Tech. In [15], the author gives an overview of wearable computing projects and discusses the applicability of user interfaces for different usage situations. Relevant application scenarios for wearable computing come from vertical markets, such as industry, public services and healthcare. Wearable electronics are more important to consumer appliances, but as well in healthcare.

4.1. Industry

Applied to industry, wearable computers are mainly used in inspection-related work processes, replacing paper-based data collection and providing hands-free data access (see section 5.1); an example for a specialized wearable computer application is pick-by-voice. In a pick-by-voice system an audio-only, speech-controlled computer system supports commissioning activities, e.g. as in distribution centers and thus makes paper lists and media breaks between analog and digital data obsolete. By freeing the hands of the person who picks delivery items, the pick-by-voice computer increases the speed and accuracy of picking processes [16].

4.2. Public services

In public services, wearable computers can be applied for mobile data collection and data access, such as mobile CAFM (Computer-Aided Facility Management), i.e. for maintaining and documenting facilities and assets. Furthermore, wearables are used for supporting police and firefighter workforces. In latter applications we see wearable electronics even today in form of body-worn sensors and alert beacons, used for locating firefighters in heavy smoke situations.

4.3. Healthcare

In healthcare, medical doctors make use of wearable computers for support during surgeries with body-worn displays providing first-hand patient data and wearable sensors monitoring human body functions. While some of these sensors are in place for many years now, connected to cables and to fixed medical equipment, future developments in wireless technology will provide sensors that can be worn in daily life. Thus, by connecting patients at home with the hospital via radio communication, patients can be discharged earlier while still ensuring constant care quality and observation of life critical data.

4.4. Consumer

Recently, all sorts of wearable gadgets are emerging, such as MP3 players and communication devices integrated into clothing [17][18] or sports gear [19]. With the integration of short-range wireless communication means, such as Bluetooth, these wearable electronics can as well connect to surrounding IT environments or to wearable computers with more functionality.

5. Research project examples

To further illustrate how research on wearable technology is approached, the following sections will summarize projects in which the author participated. Although these projects mainly involve wearable computing issues, the outcome can be easily transferred to wearable electronics as well.

5.1. Speech-controlled wearable for automotive inspections

The objectives of this project [20] were to develop a prototype of a hardware and software system that could be presented to and actually used by garage technicians, helping the project team to evaluate the needs and acceptance of future commercial systems. Therefore we took two different approaches with two different devices.

One device was based on a commercially available wearable computer – the Mobile Assistant® IV (MA® IV) from Xybernaut®. This system was a self-contained computer and exchanged inspection data via a wireless network. This first generation prototype was called SCWC 1 (Speech-Controlled Wearable Computer 1, see Figure 3).

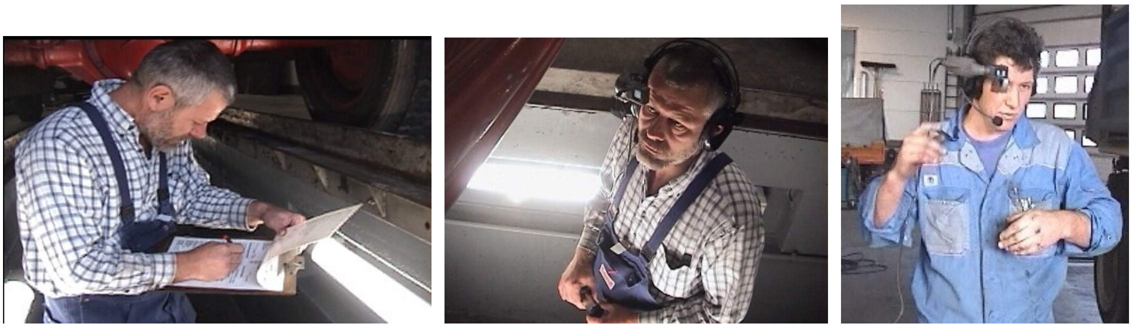

Figure 3 Garage technicians with paper-based process (left) and using the SCWC 1 with a head-mounted display (middle, right)

The second device was a proprietary hardware system developed during this project in cooperation with Bosch. Here, a remote server provided the processing power and the memory necessary to run the actual inspection application software. This server could simultaneously handle up to four clients and could be any standard desktop computer available in the repair shop, even the computer at the main office. This second generation prototype was called SCWC 2 (see Figure 4).

The idea was to investigate the relative acceptance of two different systems by service technicians with two approaches: 1) a bigger, more complete system; and 2) a smaller system that provided the same information in a more resource-efficient way (with respect to size, weight and cost). This would enable the development of a device that could be used for future inspection-related tasks in the automotive industry and similar domains.

Figure 4 (left to right) SCWC 1 graphical user interface, text-based LCD display of SCWC 2, hardware comparison of SCWC 1 (left in third image) and SCWC 2

During the design of the two systems, we interviewed the targeted users, who were real service technicians at repair shops actually performing the inspections without IT support and supported by the first, self-contained prototype of this device, the SCWC 1. This first prototype was based on commercial off-the-shelf hardware and enabled us to perform field tests before the actual implementation of the final design of the second prototype, the SCWC 2. Thus, we got valuable insights into the requirements for the hardware and software design crucial for the success of the next version of this product.

The functionality provided by this system was completely speech-enabled and thus could be operated hands-free. This functionality included: access to centrally entered vehicle and order data; hands-free data collection in the garage environment; remote control and access of measurement devices; communication with other service technicians or repair shop personnel; remote data access; or remote automation control via modem. These functionalities were all directly usable from the mobile unit. The conditions, in which the devices were intended to operate, were typical shop floor conditions, with technicians who had oily hands, a high ambient noise due to running vehicle engines, and bad lighting in and around the pit. The technicians were familiar with using the central computer that stands near the pit, but did not use mobile or wearable computers during their work before that project.

The performed field tests of the first generation prototype showed a moderate to good acceptance by the inspectors. They liked the idea to get assistance during work but were mostly dissatisfied by the size and the weight of the at that time available Xybernaut® system. Since these vehicle inspectors have to move within the pit and sometimes need to crawl into the wheel cases of trucks, they were also concerned about damaging the system or being restricted in their movement. On the hardware side they expressed the desire to have less cabling and an easier attachment of the wearable system. After rejecting the head-worn display completely and using the flat-panel display, inspectors seemed to like a smaller display and said they did not need a full graphical user interface. Thus, we developed the second prototype with a wrist-worn display that only provided the inspection list. Technicians preferred this system over the SCWC 1, because it was less obtrusive towards their work activities.

The performance of the speech recognition system (ASR 1600 from Lernout & Hauspie) was very good in moderate conditions and acceptable even in worst conditions, such as the noisy garage environment with a truck engine running. Recognition rates were estimated above 98%, even in noisy environments.

Using a speech-controlled application for the first time, and especially using a new application in a familiar environment, caused a few irritations with, and negative attitudes towards the system. Since the structure of the system was different than that of the software they used to enter data into, inspectors found it difficult to navigate within the system. It took some time to find specific inspection items by only using speech commands. Several reasons for this problem were identified:

- The hierarchical structure of the inspection data, which was taken from the standard data sheet of the paper-based inspection system;
- The need to scroll within selection lists using speech commands; and
- The lack of a general search functionality to locate and directly access specific inspection items.

To date, several companies investigate the use of speech-controlled devices for (automotive) inspections, either with thin client wearable computers, or with wearable electronics in form of wireless headsets for speech-control via audio channels.

5.2. Business Process Modeling in MRO applications

During the research of the past years, the author and his research partners, developed several approaches to document and evaluate the processes of target applications. We realized that using Business Process Modeling (BPM) to decide about the right configuration of wearables for certain usage situations could be beneficial.

While talking to companies about applying wearable computers to support MRO (Maintenance, Repair and Overhaul) processes, we learned that most of them manage their MRO data by using enterprise resource planning (ERP) systems, such as SAP R/3 or PeopleSoft®. While developing and testing prototype systems for these companies, we consulted with different divisions to define and agree on the best way to integrate the mobile IT solution into their ERP system. During this time, we analyzed work processes, defined the structures and interfaces for data exchange, and finally designed the hardware and software concept for the wearable computer system.

In order to standardize these steps and to reuse them for other projects, either within the company or with other companies, we proposed to represent this additional information concerning mobile IT usage within a Business Process Model [21]. That way, existing process models can be reused and applied to new business processes. Furthermore, different views on the processes can be provided that allow each project participant to enter and review the parts of the model relevant to his / her role within the project.

For a case study on that topic, we described a portion of a project on which we worked with a machine manufacturer that is introducing wearable computers for its MRO processes. This machine manufacturer has hundreds of pieces of machinery and a fleet of several hundred transportation vehicles that need to be maintained. All MRO activities are managed with the SAP R/3-PM module for plant management. This means that a wearable computer system which handles MRO data and supports MRO processes needs to interface with SAP-PM. Our objective in this project was to change their paper-based data collection processes to computer-supported processes using mobile and wearable computer systems. As part of this project, we modeled the underlying processes with the BPM tool ARIS [22], including the actual work situations - mostly data collection tasks.

We modeled an MRO process, using an extended Event-driven Process Chain (eEPC) diagram. Figure 5 shows an overview of a maintenance process from the moment the maintenance request arrives at the shop to the moment the maintenance is performed and documented.

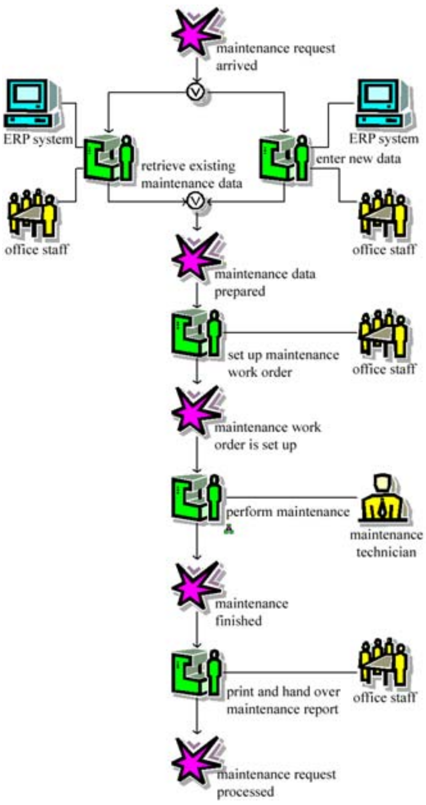

Figure 5 Industrial process eEPC of a maintenance process

With the help of this eEPC, one can quickly identify the needed resources and participants of the process. It does not yet define the maintenance method, or the single steps that the maintenance technician will perform, but it offers the links to corresponding, more detailed diagrams that contain information about the environment and the constraints on the wearable computer system that arise in a specific situation. Based on such an analysis, we can identify the requirements for the proposed wearable and the needed interfaces to its surrounding (ubiquitous) computing environment.

6. Outlook: potential of wearables

While the consumer market is already emerging with self-contained wearable electronics, there is still great potential for wirelessly networked wearable electronics and next-generation wearable computers. In a study dated October 2000, which still proves to be current in most parts and which the author reconfirmed with Gartner, Gartner analysts predicted: "Among the key enablers for IT-related business processes and consumer interactions in the first decade of the new century will be always-on, wearable communications and computing devices. Beside communication, the major drivers of this vast always-on trend will include entertainment (video, audio and real-time games) and health monitoring". [23] Until we see such devices being fully connected to the ubiquitous computing world, they will be offline, asynchronously updated units, such as MP3 players that can be connected to a computer to upload new music files. With network access, such devices can access online content immediately.

Wearable computers have been on the market for several years now and still deployment lags behind expectations. After exorbitant predictions around the turn of the century, analysts see a more realistic, but still promising future for wearables. For 2007, Venture Development Corporation (VDC) predicts shipment of wearable computer form factor products to grow to four to eight times the actual shipment of 2003 [24]. Figure 6 illustrates likely and optimistic predictions [25]. The breakthrough for such devices will be reached, when the research challenges mentioned earlier will be solved and incorporated into commercially available systems. Furthermore, all stakeholders in the wearable technology market have to set up promising application scenarios, educate industry by allowing and supporting early pilot projects and by setting up business use cases that help companies to see the ROI potential beforehand.

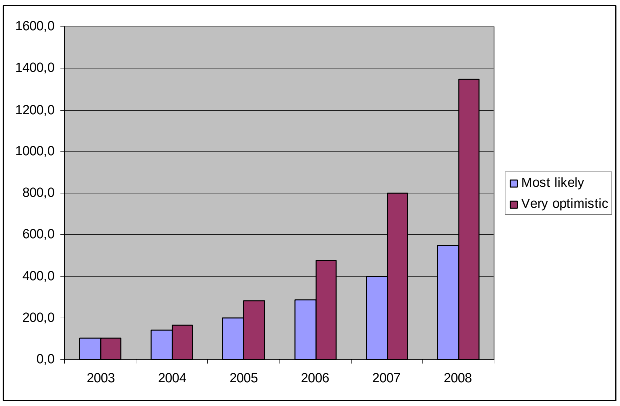

Figure 6 Worldwide Shipment and Forecast in (million US$) for Wearable Computer Form Factor Products, according to VDC

For wearable electronics the central communication hub might probably be the mobile phone or a similar communication device. Electronic components will connect to this hub either wirelessly or with in clothing integrated cables and circuitries. Thus, once this functionality becomes more widespread, every electronic module worn on the body can add value by offering wireless connectivity or standardized interfaces to connect and make use of offerings available on the network. Vice versa, information can also be pulled from the users of networked wearables, as the Gartner study continues: "Customer-oriented communities and consumer profiling will likely give enterprises an improved understanding of their customer bases and lead to new revenue opportunities through new products and services." Hence, new business models and application scenarios have to be designed by hardware and software developers and providers of online content and mobile services. The telecommunication industry needs to provide the connectivity infrastructure and business models that allow for these future applications.

Speaking with the words of Geoffrey A. Moore [26], one can say that wearable technology is right before "crossing the chasm" and thus, wearable industry needs to further develop their products to develop the mainstream market for wearable computers and wearable electronics.

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