Markus Aleksy and Mikko J. Rissanen. Utilizing Wearable Computing in Industrial Service Applications. Journal of Ambient Intelligence and Humanized Computing (JAIHC), 2012. Springer. DOI: 10.1007/s12652-012-0114-2

Authors' version. The original publication is available at www.springerlink.com

Utilizing Wearable Computing in Industrial Service Applications

Markus Aleksy[1] **Mikko J. Rissanen**[2]

[1] ABB Corporate Research, Industrial Software Systems Program

Wallstadter Str. 59, 68526 Ladenburg, Germany

e-mail: markus.aleksy@de.abb.com

[2] ABB Corporate Research, Industrial Software Systems Program

Forskargränd 7, 72178 Västerås, Sweden

e-mail: mikko.rissanen@se.abb.com

Abstract Wearable computing promises to gain efficiency improvements in industrial applications due to augmentation of the device as well as improved interaction between the user and the device. In this paper, we present the results of a study with focus on utilization of wearable computing in industrial service applications. Our study consisted of a preliminary market scan with regard to wearable computing devices and literature analysis that has been conducted to find out where wearable computing is already used or is well suited for industrial service applications. Additionally, we carried out a case study at an industrial plant to figure out which of the existing service processes can be improved by wearable and mobile devices and show how it could be done. Finally, we discuss the desired developments that would enable wearable computing to enter the practice of industrial service.

Keywords Wearable computing, Mobile computing, Industrial field service, Case study

1 Introduction

Proper service is a key component of making industrial plants work without unexpected shutdowns and safety hazards to workers. Service work consists of repair and maintenance tasks to fix electrical or mechanical devices and management of appropriate information needed for each specific service case, such as handbooks, how-to and best-practices guides, decision trees, error-codes etc. This data is processed slowly because of time consuming media conversion and paper work before and after the actual service work. Service engineers are well trained to service the particular device or system area, but in complex and rare service cases additional information, such as best practices and supporting software tools, are required to support problem solving at the worksite. One specific service case is so called ‘‘site audit’’. In these situations the information must be collected to outline the current state of the device and a set of tools is used to calculate and outline how the plant health and safety could be improved and guaranteed. Hereby, service experts must be physically present at a site.

When a customer, who often is a layman, identifies need for a service, it can be difficult to describe the current case. The service providing company needs information about the installed faulty equipment and potential error codes to give the customer a first hint about a potential solution. Service engineers are quite often required to come to the work site for trivial cases because all the necessary information had not been available in advance.

Wearable computing may provide considerable improvements to the aforementioned areas of industrial service. Many of the proposed solutions designed originally for the healthcare domain (for example Ohmura et al. 2006; Olguin et al. 2009) and military domain (e.g., Zieniewicz et al. 2002) have technological similarities with what wearable computing for industrial services would require. Wearable computing was assumed to make a breakthrough in the industry almost a decade ago

Markus Aleksy and Mikko J. Rissanen. Utilizing Wearable Computing in Industrial Service Applications. Journal of Ambient Intelligence and Humanized Computing (JAIHC), 2012. Springer. DOI: 10.1007/s12652-012-0114-2

Authors' version. The original publication is available at www.springerlink.com

(Stanford 2002), yet, device costs and technical reliability today are still serious obstacles for wide-spread practical applications. As the healthcare domain has great demand for safety and in the military domain effectiveness and tactical advantages are pursued for, a typical industrial service organization cannot afford all the latest technology without certainty of return of investment. Predictability has a key role in investment decisions when considering of applying new technology. It is difficult to convince for example a manager of process automation service to invest $4,000 in a head-mounted display (HMD) for each of his 2,000 service engineers which would make a total cost of 8 million dollars if there is a risk of not improving the overall efficiency in the organization. Wearable computing has still not really been proven to provide adequate ergonomy, technical reliability and general practicality in a way plant management would not have any doubts about. Cost-efficiency drives the industry. The price class of a smart phone is expected to be a good approximation of acceptable costs in comparison to the risk, since nowadays many companies offer smart phones to their employees as standard work equipment. Today, industrial services require well demonstrated and proven solutions to be worth the investment.

This paper presents the results of three studies. At the beginning, we present a preliminary market scan regarding wearable computing devices in order to gain understanding of the scope of investment required to make wearable computing real in industrial service. Second, we show a literature analysis that outlines application scenarios and use cases for industrial service applications. We discuss the approximate costs and technical capabilities of the devices to practical use cases presented in other studies in relation to practicality and near-future prospects of wearable computing applications for industrial services. Third, we summarize a case study conducted in a pulp and paper mill which consists of analysis of most prominent use cases that show high potential for improvements by proposed wearable computing applications. Specifically, we show two improvements: wearable computing support for isolating parts of the plant before service work commences, and improvements to ensure worker safety using an automated safety suit.

2 Wearable computing devices—state of the art

In the first phase of our study, we evaluated existing commercial wearable computing devices that could fit industrial service processes as technological support. Technical capabilities as well as price of each device type have been considered. Here, we summarize conclusions for each category of devices and present representative examples:

• Output devices Sensics carried out a market survey of HMDs in 2008 (Boger 2008). They survey shows that the ‘‘good enough’’ HMDs do not yet exist. The situation has not been improved much since if the aim is practical augmented reality application. Nowadays commercially available HMD-based output devices are still bulky and ergonomically questionable for wide scale industrial applications. Latest devices such as i-glasses 920HR are getting near to the acceptable price level and practicality but lack video camera functionality and is thus designed merely for watching image and video content and for not augmented reality. High-quality products that are both practical and ergonomic, such as HMDs designed for military use, are still too expensive to be considered for cost-oriented industries. Next-generation OLED microdisplays and retinal displays can solve the practicality issues in the next few years but the cost may still be around thousands of dollars per HMD. Some of the HMDs that have been demonstrated in fairs and conferences, such as AR Walker from NTT DoCoMo and TeleScouter from NEC set high expectations for the next generation HMDs. Considering just the price, today’s low-cost applications of a few hundred dollars can be built on wrist-worn conventional TFT-LCD displays, such as IDView’s IV-2535D wearable monitor, but have limitations in practical use because both hands are needed for using the device.

• Wearable video cameras and eye/head-trackers Low-cost wearable video cameras that have emerged in the markets provide acceptable level of resolution and framerate. For example, You-Visions video glasses provide 640 9 480 pixel recording at 25 frames per second at a price of $150. Looxcies offering is similar. Vuzix offers a Wrap 920AR package around $2,000 that consists of near-eye 2D/3D video see-through display and video recording embedded in an eyeglass frame. Additionally, gyro and acceleration sensors enable head tracking in the same hardware design. Wearable video cameras today can be considered to be robust, reliable and available for reasonable price, but battery life that is often limited for some hours is still seen as a technical limitation. Tobiiglasses are a comprehensive solution including eye-tracking capabilities and an analysis software at a package price of $45,000 which is intended mainly for market research purposes. All video cameras equipped with eye-tracking are expensive. Future developments in the prices may be due to increased competition between vendors. Mere head-tracking features are already affordable. Only plain video cameras are considered to be affordable for industrial service.

Input and sensing devices Wrist-worn keyboards such as FrogPad or WristPC from L3 Systems intended for portable computer use are practical options in the price class of a few hundred dollars. They, however, are not truly wearable since they require one hand to be still and the other hand to be used for typing. Wrist-worn keyboards are mainly intended as extension to mobile phones and such consumer electronic devices. Data gloves are still expensive. For instance CyberGlove II Wireless from METAmotion and PINCH Gloves from Fakespace Labs cost several thousands of dollars, for which they are suitable for research purposes mainly in stationary virtual reality platforms. Also full body motion tracking is strictly limited to lab use and costs tens of thousands of dollars. Cheap input devices can be made by attaching latest gyro, acceleration and inertia sensors (as for instance suggested by Crossan et al. 2008), e.g., B-Pack WAA006, to arms at a less than $500, but such

Markus Aleksy and Mikko J. Rissanen. Utilizing Wearable Computing in Industrial Service Applications. Journal of Ambient Intelligence and Humanized Computing (JAIHC), 2012. Springer. DOI: 10.1007/s12652-012-0114-2

Authors' version. The original publication is available at www.springerlink.com

interfaces will have limited and non-standardized operability by the user compared to wrist-worn keyboards.

• Wearable PCs Wrist-worn PCs offer Windows or Apple style interaction with a full computer. A representative example of a wrist-worn PC is W200 from Glacier Computer and the latest WIMM One. This kind of full computer capability attached to the wrist, including a small keyboard is far from wearable computing ideals. Head-mounted computer concept demonstrated such as Motorola's Golden-i is a promising and technically capable approach. A full PC platform is mounted on the user's helmet. Voice recognition as well as head tracking serve as the input and LCD display as the output mechanism. This kind of comprehensive platforms can be expected to give a boost to many kinds of wearable computing applications as long as the price can be kept around conventional laptop computer prices, i.e., around $1,000.

3 Wearable computing in industrial applications

In the second phase, we conducted a literature review and analysis. We used the Scopus database (http://www.scopus. com/) for an initial investigation with regard to the utilization of wearable computing devices in industrial applications. Search queries are listed in Table 1 and Fig. 1).

Based on these results we analyzed the literature further. We also supplemented the results with additional queries to Scholar Google (http://www.scholar.google.de/). In the following we list categories of use cases in industrial service from previous literature and give representative examples of each category.

• Maintenance tasks. Nicolai et al. (2005) present an approach for combining wearable computing and knowledge management. They expect to shorten the maintenance process in the aircraft industry. In further work (Nicolai et al. 2006) the authors identified functionality to support the service engineer with relevant information and documentation, such as logbook and self-diagnosis overview, detailed defect reports, manuals, location list, defect reports of similar cases, navigation through error classification, expert contact information. Additionally, writing repair reports could be improved. Interviews with users showed that identification of required maintenance, finding job-related documents, and documenting the work as subtasks could be improved utilizing wearable devices. Ishii et al. (2007) proposed an augmented reality system which was built on a tablet PC and a pen user interface to support maintenance of nuclear power plants. They also performed a preliminary evaluation of the system's usefulness in decommissioning tasks. The evaluation proved to provide some ease-of-use to the task but as the platform was not truly wearable user interface it is difficult to estimate its true benefit in saving time for the service engineer. Siewiorek et al. (1998) focused on train maintenance and diagnosis and developed a support system that utilizes mobile information and communication technologies. Their prototype enables maintenance personnel at the worksite to communicate with a remote helpdesk or expertise center. Use of digital data, audio and image, supports preventive maintenance activities and handling of unusual faults. Baudhuin (1996) developed a concept a wearable computers and interactive electronic manuals that would support maintenance personnel in the military domain.

• Quality assurance inspections. Najjar et al. (1997) studied a food processing plant as an application domain and developed a wearable voice-operated computer for quality assurance inspectors.

• Activity tracking. Stiefmeier et al. (2008) created a context-aware wearable computing system for supporting production or maintenance workers in automotive industry. Their system recognizes the worker's actions and delivers just-in-time information about activities that are to be performed next.

• Collaboration between pairs of users. Siegel et al. (1995) present an empirical study of aircraft maintenance workers. In computer supported cooperative work, wearable computers have often been utilized to aid service engineers in a certain task.

• Wearable communities and social networks. Kortuem and Segall (2003) discuss the potential of wearable computers in social networks and proposed general design principles for ‘‘wearable communities’’.

• Proactive instructions for assembly tasks. A framework for pro-active assembly instructions was proposed by Antifakos et al. (2002). Their aim was to overcome the limitations of today's printed and computer-based instructions in furniture assembly. Their approach is based on attaching several computing devices and multiple sensors onto different parts of the assembly and let the system recognize the user's actions, determine the current state of the assembly and provide helpful guidance at the right moment.

• Hands-free documentation. Ward and Novick (2003) introduced an analysis of general requirements and design choices for hands-free documentation. They considered corresponding roles and characteristics of different input and output modalities such as speech.

Table 1. Wearable computing related publications found using Scopus

Year	Query 1[a]	Query 2[b]	Query 3[c]	Query 4[d]	Query 5[e]	Query 6[f]
1995	1					
1996	4					
1997	12					
1998	6					
1999	11				1	
2000	19	1				
2001	22	1				
2002	24					1
2003	41	2	2	3		2
2004	57	2		1		
2005	48					
2006	48	2	2	2		
2007	90	9	4	5		1
2008	77	4	2	2		1
2009	67	4		1		1
2010	67	4				3

[a] TITLE-ABS-KEY (“wearable computing”)
[b] TITLE-ABS-KEY [“wearable computing” AND (“industrial application” OR “case study”)]
[c] TITLE-ABS-KEY [“wearable computing” AND (“aerospace” OR “avionics” OR “aircraft maintenance” OR “aircraft assembly”)]
[d] TITLE-ABS-KEY [“wearable computing” AND (“aerospace” OR “avionics” OR “aircraft”)]
[e] TITLE-ABS-KEY [“wearable computing” AND (“factory automation” OR “plant automation”)]
[f] TITLE-ABS-KEY [“wearable computing” AND (“car manufacturing” OR “automotive”)]

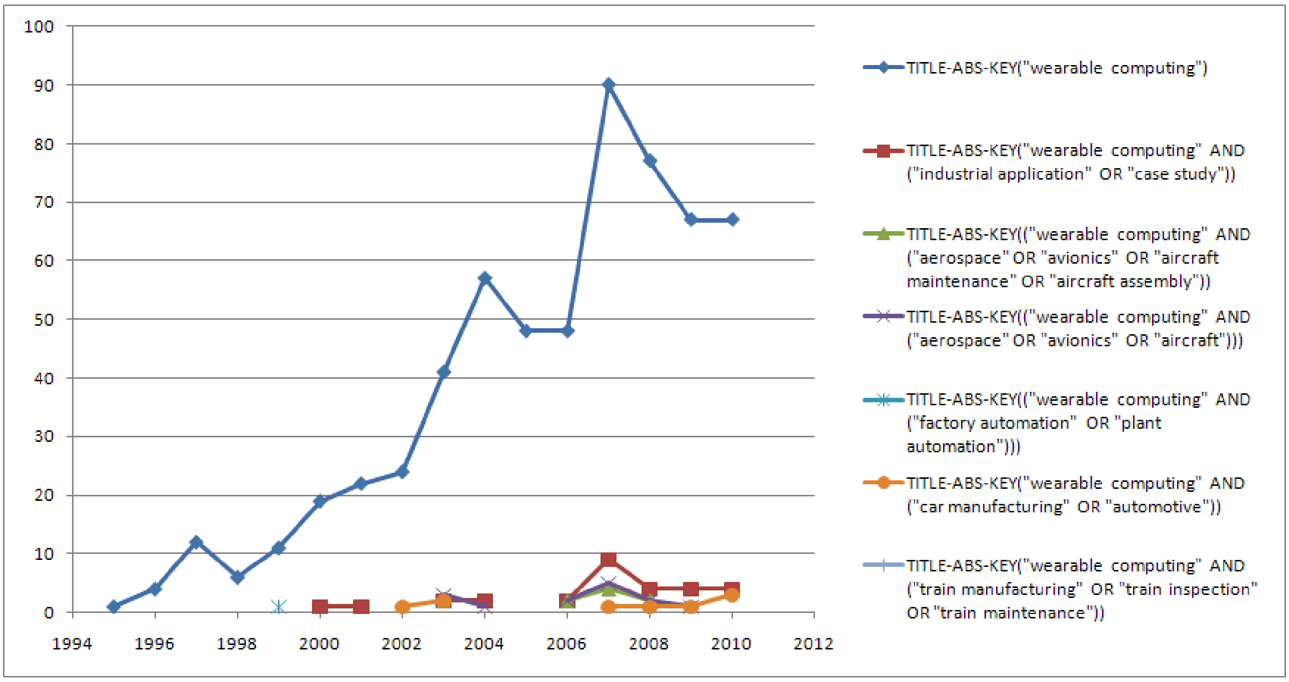


Fig. 1. Different types of wearable computing related publications

• Opportunistic sensing. Opportunistic sensing (Roggen et al. 2009) allows a system to collect information about the physical world and the persons behaving in it which then can be used for providing helpful information in a context-sensitive manner.

• Mobile E-meeting. Drugge (2006) investigates the support for mobile e-meeting through wearable computing for e.g.,electricians working at remote installations and analyzed for instance cognitive load of interruptions and errors in primary and secondary tasks.

In addition, Bürgy (1999) compiled a list of projects that focus on wearable computing and augmented reality. The described use cases include support for vehicle inspections, crane operator assistance, end-of-line inspections in manufacturing, bridge inspections, and inspection of manufacturing machinery.

There is little information with regard to successful application in industry. As one of the earliest reports, Stein et al. (1998) demonstrated a commercially successful wearable device that was utilized by United Parcel Service. Concurrent studies that report deployment of prototypes in the real world in the industry are few.

Also economic evaluations of wearable computing require further investigation. Besides a few articles and case studies that report efficiency improvements of 50 % (Computerzeitung 2005) or even 70 % (Guardian 2000) in some industrial service tasks, little is known about the real long term impact of wearable computing on industrial working environment and, thus making further research necessary. To respond with this demand, we carried out a case study in a pulp and paper plant to evaluate the potential of wearable computing in industrial service.

4 Case study

The case study was carried out in 2011 in a pulp and paper mill located in a rural area and serviced by more than 100 service engineers.

4.1 Case study design

We chose Kepper's qualitative case study methodology (Kepper 1999) to provide us a holistic description, interpretation, and understanding of relationships and requirements of the service process phases. We interviewed domain experts such as service engineers, as well as contact center agents to collect details about the current service process. The interviews have been performed according to the semi-structured interview guide of Yin (2003), complemented by personal face-to-face interviews as suggested by Frey and Oishi (1995). This approach helped us to reduce possible misunderstandings during the process of information gathering. Additionally, workshops with participants from several service business units, such as service engineers, safety and quality officers and other domain experts, have been organized to verify and validate the collected service process information. This resulted in a broad understanding of the requirements, challenges and optimization opportunities.

All in all, 39 possible use cases related to improvement of the work processes, safety and quality processes, supply chain management, and reliability-related activities, were identified. In the following section, we focus on two of the identified use cases and describe the opportunities that low-cost wearable devices can provide some benefit to.

4.2 Use cases for wearable computing in industrial service

During our face-to-face interviews and workshops we evaluated eight application areas, namely service planning, service execution, reliability activities, human resources, supply management, communications, quality, and safety. In a second step, additional interviews and workshops were carried out to prioritize the identified use cases. Afterwards, we selected the most promising use cases as candidates for a detailed evaluation. The Plant Isolation and Safety Assurance use cases were among of our favorites. They are described in detail in the next sections in terms of the current process (as-is) and the future improved process (to-be) that is supported by a wearable computing solution.

4.3 Plant isolation

The first identified improvement area is related to the plant isolation use case. The plant owner is responsible for ensuring all employers to meet their health and safety legal responsibilities. An industrial plant has an isolation system to protect people working on plant or equipment. This means that a part of the electrical system is turned off in a controlled fashion before fixes or preventive maintenance work starts on that part of the system. This is done to ensure safe service work and minimal disturbance to the plants operation. The isolation system can be used by several individuals.

4.3.1 As-is process

Nowadays, plant isolations are often done by utilizing paper-based forms that the field engineers have to carry to the worksite and fill as post-work report. Work orders and related activities, such as isolation lists are mainly stored in an asset and maintenance management software system. In case of plant isolation activity, sticky labels, sign-on/sign-off cards, and ticket lists are created. Sticky labels are used to mark the involved equipment, i.e., making them visible to everyone that they are being serviced. Sign-on/sign-off cards are used to keep track who is visiting the isolated area. Everyone who enters the

Markus Aleksy and Mikko J. Rissanen. Utilizing Wearable Computing in Industrial Service Applications. Journal of Ambient Intelligence and Humanized Computing (JAIHC), 2012. Springer. DOI: 10.1007/s12652-012-0114-2

Authors' version. The original publication is available at www.springerlink.com

isolation area has to sign-on and to sign-off leaving the isolated area, respectively. This procedure ensures that nobody is inside the isolated area should the production start again accidentally. The ticket list ensures that all corresponding activities have been finished, i.e., that all of the sticky label have been attached. Figure 2 shows the corresponding business process.

During the analysis we realized that this service process can be improved due to the fact that some of the aforementioned activities still rely on paper-based documentation. The localization of the equipment to be isolated as well as the current sign-on/sign-off procedure of the isolated part of the plant can be significantly improved.

4.3.2 Improved process

The improvement areas are related to the location of equipment that has to be isolated and to the sign-on/sign-off procedure. Here, service personnel performing plant isolations is equipped with wearable computing devices with positioning system and WiFi connectivity, and optionally with a camera and an electronic compass. The wearable devices receive a plant isolation list containing all equipment (incl. location information) that has to be is isolated via WiFi from an asset and maintenance management system. The location information of the wearable device is obtained automatically via GPS in case the corresponding signal can be received. Otherwise, other positioning approaches such as based on GSM/UMTS segments or antennas or beacons can be utilized (cf. Want et al. 1992; Bahl and Padmanabhan 2000; Priyantha et al. 2000; Castro et al. 2001; Youssef and Agrawala 2005; King et al. 2006; and others). The viewing direction is detected by an electronic compass. The locations of the equipments that are to be isolated are shown on the display of the wearable device.

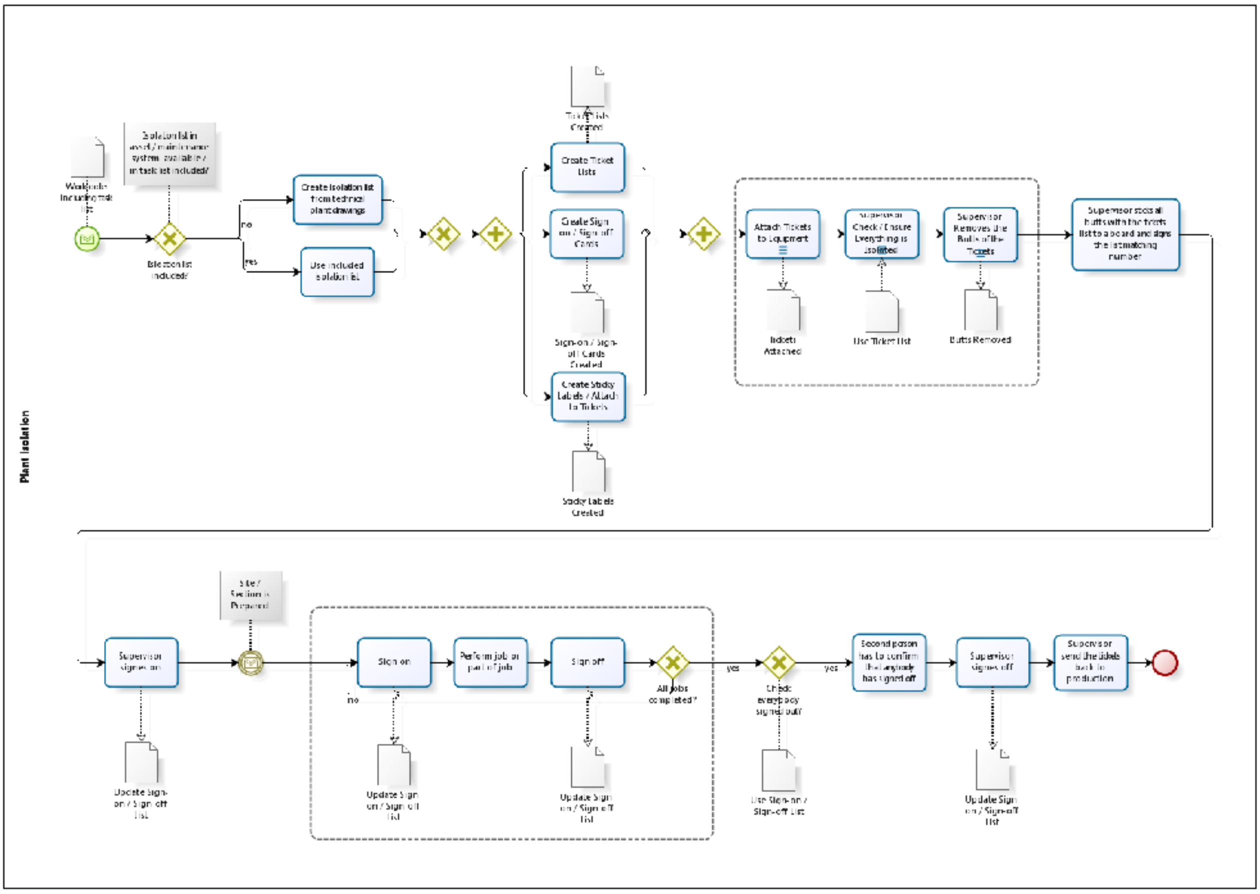


Fig. 2. As-is plant isolation process

Here, blueprint-based (cf. Fig. 3) or augmented reality-based (cf. Fig. 4) visualization can be utilized. Thus, localization of relevant equipment is expected to become more efficiently as indicated in the preliminary study of Shimoda et al. (2004) that targeted isolation of water valves in nuclear power plants. Each device is first isolated from the other parts of the system and then marked as isolated physically and electronically. The wearable device gives feedback after all relevant equipment has been isolated and marked as isolated. The same method can be utilized to discover equipment for which isolation should be

Markus Aleksy and Mikko J. Rissanen. Utilizing Wearable Computing in Industrial Service Applications. Journal of Ambient Intelligence and Humanized Computing (JAIHC), 2012. Springer. DOI: 10.1007/s12652-012-0114-2

Authors' version. The original publication is available at www.springerlink.com

removed after successful execution of the maintenance work.

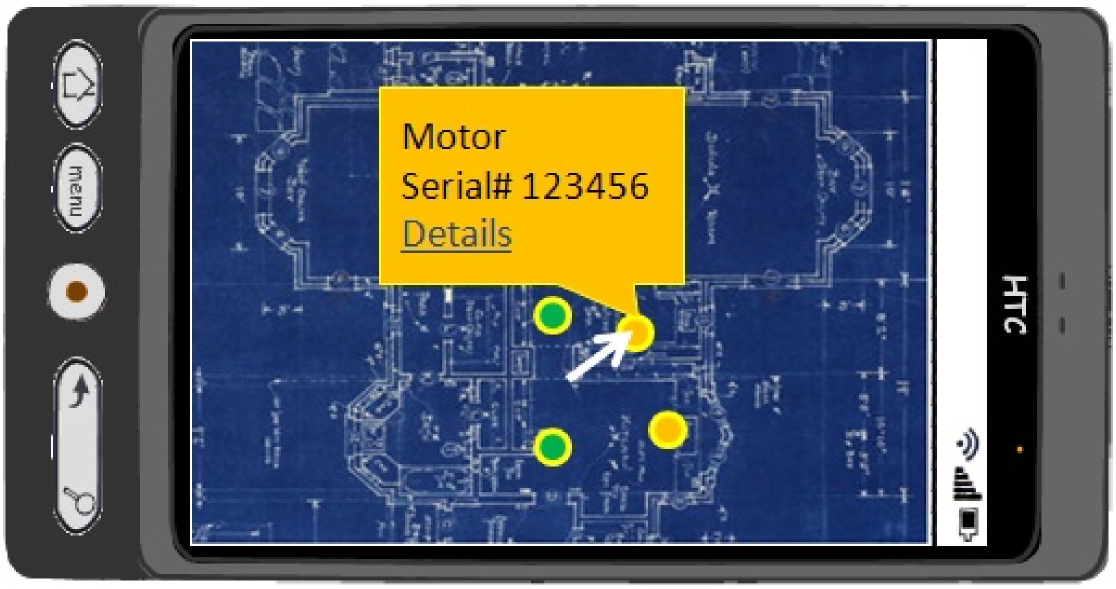


Fig. 3. Blueprint visualization of equipment to be isolated

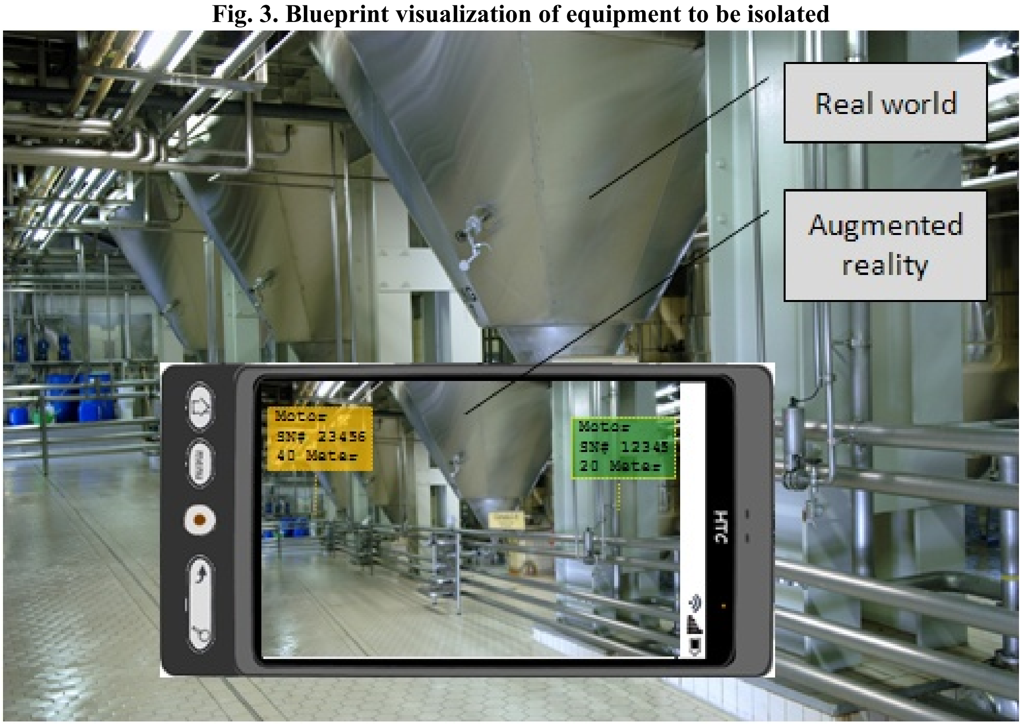


Fig. 4. Augmented-reality visualization of equipment to be isolated

The basic plant isolation support system can be enhanced by an electronic tag included in the wearable device or attached to it, thus improving the sign-on/sign-off procedure. The wearable device is personal and contains each service engineers employee number as an identification measure. Each time a service engineer equipped with the wearable device enters the isolated area, the electronic tag is detected by the electronic tag reader attached to the entrance of the isolated area. The person identified is marked as signed-in in the asset and maintenance management system. The same procedure is utilized each time a person equipped with the wearable device leaves the isolated area. Here, the electronic tag is detected by the electronic tag

Markus Aleksy and Mikko J. Rissanen. Utilizing Wearable Computing in Industrial Service Applications. Journal of Ambient Intelligence and Humanized Computing (JAIHC), 2012. Springer. DOI: 10.1007/s12652-012-0114-2

Authors' version. The original publication is available at www.springerlink.com

reader attached to the exit of the isolated area. The person identified is marked as signed-off in the asset and maintenance management system. Other people can use their wearable devices to check if everybody is marked as signed-off before the isolation tags are removed. This provides for a fully automated safety function. Figure 5 shows the improved plant isolation system.

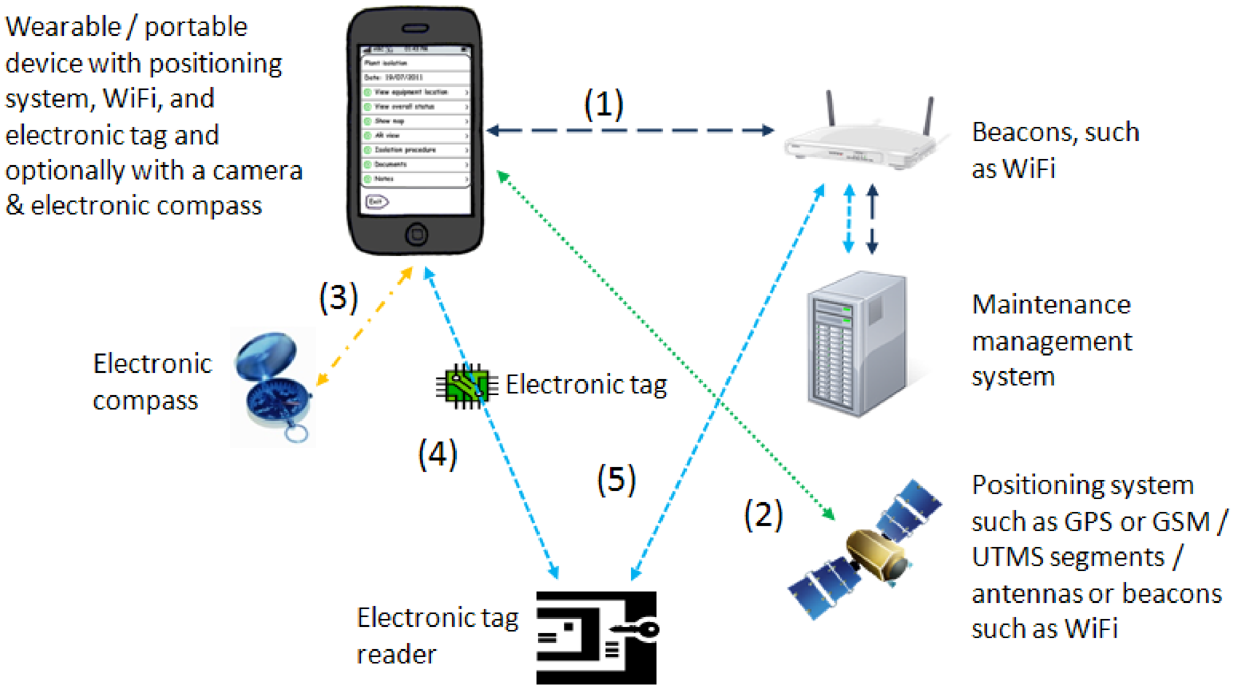


Fig. 5. Improved plant isolation system

4.4 Safety assurance

The second area identified for improvements is related to work safety in terms of recognizing dangerous situations and communicating about them to other service personnel. Normally, the environment where service work is conducted varies from safe to hazardous. Gas leaks and radioactive materials pose a significant risk to the service personnel who are taking care of maintenance and repair duties on-site. Sometimes the worksite is small and constrained, such as narrow spaces between buildings, manholes, pipes or other cavities. These kinds of worksites are called “confined spaces” which as such are considered to be risks to safe service work. Work in confined spaces requires extra careful procedures and protective measures.

4.4.1 As-is process

Today, there are several kinds of safety standards, procedures and checklists to minimize safety risks. Checklists and post-repair documentation is usually done on paper and turned into a digital archive manually afterwards.

Safety measures are taken to the extreme to ensure safe repair work especially in confined spaces. First of all, in a well-conducted service work there is always a named supervisor who is in charge of correctness and safety of the repair work of a team of service engineers. The supervisor usually has most experience of difficult repairs and manages detailed planning of the actual repair work. Second, a “door watch” person is set on the door or other entrance point to make sure that the service engineer taking care of the dangerous situation is safe, others do not enter the worksite without permission and nobody does anything dangerous accidentally without knowing the situation. The door watch is also responsible for calling for help in case of an emergency. After an accident it is sometimes difficult to know what went wrong and a lot of paperwork is needed to document the accident so that it can be avoided in the future. Simple tools such as helmets and safety boots as well as protective eyewear, gloves and clothes are used to protect the service personnel. More advanced tools include oxygen level, gas and Geiger meters which are used in most dangerous cases. Oxygen levels are to be measured on three levels, head, waist and feet, in order to guarantee breathable air at the worksite. Safe limits are defined in work safety standards created by organizations such as Occupational Safety and Health Administration (OSHA 2011) in the United States. Mobile phones or radios are used for calling help. Mere equipment does not improve safety as such without the safety standards, procedures and protocols.

Markus Aleksy and Mikko J. Rissanen. Utilizing Wearable Computing in Industrial Service Applications. Journal of Ambient Intelligence and Humanized Computing (JAIHC), 2012. Springer. DOI: 10.1007/s12652-012-0114-2

Authors' version. The original publication is available at www.springerlink.com

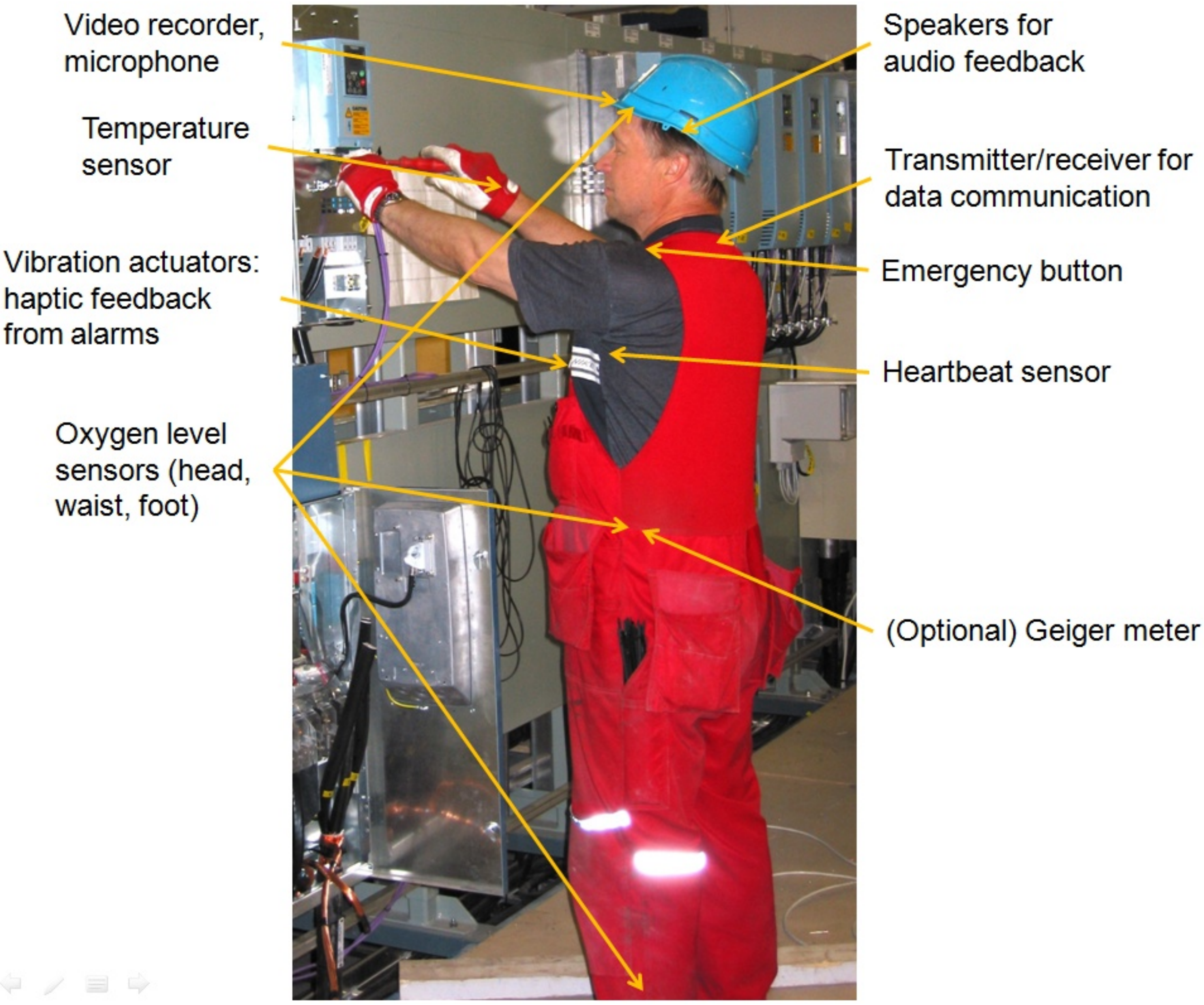
Especially in confined spaces manual safety measures are taken to the extreme to ensure safe repair work. Door watch person is set on the door or other entrance point to make sure the service engineer taking care of the dangerous situation is safe and nobody accidentally does anything dangerous without knowing the situation. The door watch is the person who calls for help in case of an emergency. After an emergency it is sometimes difficult to know what went wrong and a massive paperwork is needed to document the accident.

In case the service engineer working in the confined space is in risk of losing his life, it is often the door watch who becomes an additional casualty when entering trying to save the person in trouble. This is unfortunately the most typical reason for losing several lives in a serious accident that occur in confined spaces. In many cases even if the door watch is assigned to guard the entrance, he is unable to see clearly what is happening inside the confined space because of obstacles on the way between the entrance and the service engineer.

4.4.2 To-be process

A wearable automated safety suit that includes various kinds of sensors and a user feedback system records readings from the meters and sensors and then alerts the service engineer himself, the door watch and his supervisor in case of dangerous situation. At the same time, the recorded data works as documentation which is useful for post-work accident/incident analysis.

Figure 6 illustrates features of the automated safety suit which consists of sensors and feedback devices connected by a body-area network which in turn is connected to external systems via a transmitter-receiver unit attached to the uniform at the back of the neck.



Markus Aleksy and Mikko J. Rissanen. Utilizing Wearable Computing in Industrial Service Applications. Journal of Ambient Intelligence and Humanized Computing (JAIHC), 2012. Springer. DOI: 10.1007/s12652-012-0114-2

Authors' version. The original publication is available at www.springerlink.com

Fig. 6. Automated safety suit concept

There are several sensors embedded into the suit. First, oxygen level meters are located at three parts of the body corresponding to the recommended measurement procedure: head, waist and foot. Temperature meter is attached to the service engineers wrist of his dominant hand and a heartbeat meter is attached to the chest. For plants where radioactive waste is produced a Geiger meter is added to the waist level sensors.

As mundane but mandatory features, attached to the helmet are video recorder, speakers and a microphone which enable communication between the service engineer, the door watch and the supervisor even inside the confined space. In addition to auditory feedback, vibration actuators attached to the chest provide haptic feedback which is used to display multimodal alarms.

Finally, the suit is equipped with an emergency button that is located on the front side of the non-dominant hands shoulder. The emergency button enables the service engineer to call for immediate help even if the door watch or supervisor cannot directly see or hear the situation. The emergency button is a must-have feature already in today's mobile applications that are used in repair work out in the field.

As most of the dangerous situations are predefined in international safety standards, the sensors can be set to trigger alarms on preset limit values. Warning messages about lowering oxygen, temperature or radioactivity levels can be provided as audio messages as well as vibro-tactile messages that can be felt on the chest. Sharing of the data coming from service engineers sensors to the door watch's and the supervisor's mobile devices ensures that the work is known to progress safely or many of the dangerous situations are detected as soon as possible. Although the proposed safety suit does not remove the need for the door watch entirely, it will make the work easier as the digital data enables triggering of alarms immediately and thus faster reaction to most dangerous situations.

The proposed solution does not contain very complex components. Instead, it represents cost-efficiency by being approximately worth of a laptop and reliability by being simply and robust to set and trigger the alarms. This is the level of a state-of-the-art support to safety assurance that can realistically be implemented in an affordable way. Yet, the automated safety suit provides significant advantages to safety assurance not only in confined space work but other safety-critical in industrial service such as maintenance of devices at high altitudes or risky one man repairs. Automatic communication of the potential danger to other repair team members is a key feature of computer-enhanced safety assurance.

Utilizing Radio Frequency Identification (RFID) technology enables another approaches such as proposed by Hsu et al. (2011) that aim improving safety at home or in industrial environments.

5 Discussion

So far we have shown what devices exist in the market, what use case categories have been imagined in previous studies and what use cases we identified to be improved by wearable computing. In this chapter we discuss the desired developments and bottlenecks that have prevented wearable computing from becoming a breakthrough technology in industrial service. As our literature analysis and survey on state-of-the-art devices shows, wearable computing on one hand shows great potential for improving industrial services, but on the other hand lacks proper methodology and device base for implementation. Lack of proven cost-efficiency and profitability are yet another significant challenge for the future. Some of the main limitations for wide-scale industrial deployment in 2012 are:

• Infrastructure. Major limitation is set by non-existing infrastructure. Since the only functioning and widely deployed infrastructure is based on 3G network, smart phones and their extensions, such as Apple's iPhone and App Store, true wearable computing applications need something similar as a deployment platform. A more flexible and easily extendable platform would enable more companies to explore the true potential of wearable computing. Internet services such as Twitter are becoming more and more interesting for experimental infrastructures as shown in many recent ubiquitous computing studies, but have limitations in acceptance in the industry unless deployed as private, closed networks. General purpose small computing platforms such as Arduino (2011) can be utilized for making small and effective private networks of wearable devices but they require a considerable amount of effort to make a large scale system functional. Naturally, much of the infrastructure depends on the display devices and their ease of utilization in practical applications. In February 2012, Google announced that it will aim to release an Android based eyeglass display platform which would essentially implement the various memory glasses concept applications (see Mann 1997; DeVaul and Pentland 2000; Dickie et al. 2004). Having an open and extendable platform would enable various businesses to emerge from customization and optimization of wearable computing solutions to specific use cases in industrial service.

• Reliability. Because of the lack of infrastructure, reliability is an uncertainty that does not encourage industrial service companies to invest in wearable computing projects. Industrial standards for technology as well as operations require steady, error-tolerant infrastructure which service workers could depend on. The only reliable services available today are based on/enable phone calls and 3G data transmissions.

• Complexity. The complexity of today's wearable and ubiquitous computing applications requires additional solution approaches to facilitate the development of such applications that save time and costs in real work. This includes the ability to invisibility and fusion management, seamless integration of ubiquitous wireless networking and sensing technologies as well as management of context information to address the complexity of such applications. Although, the complexity aspect had already been identified by Kortuem (1996) as a critical factor in the development of wearable computer, there is still a lack of a comprehensive solution and tool support addressing this challenge. The complexity of a wearable and ubiquitous computing application can be drilled down to various aspects such as the complexity of nomadic information environments which is reflected in the required infrastructure and management of the corresponding services (Lyytinen and Yoo 2002), the complexity introduced by the intertwining of the adaptation and the application behaviours (Mikalsen et al. 2006), and the complexity of simultaneous management of different networking technologies (van Megen et al. 2006). The adaptation of a ubiquitous computing application isn't limited to the user's context but can also consider other aspects such as energy-awareness and thus support energy-efficient approaches (see Bajaber and Awan 2010; Enokido et al. 2011, for example).

• Cost. Devices that can be considered for simple applications are plenty and many types of devices are now becoming affordable for wide-scale deployment. Unfortunately each application is case-specific which is seen in the industry mainly as a risky investment because convincing case studies are still few. Our automated safety suit concept demonstrates a low-cost solution that could be built using rather affordable components. Commercially available platforms that could be classified as wearable computing may emerge soon in the consumer domain, but few of the developments in this direction can be expected to be applicable directly for industrial services. Currently only certain industries can afford applied science experimentation whereas others require proven cost-benefit calculations before making investment decisions.

In short, in order to make a breakthrough in wearable computing in industrial service industries, applied science sector has to produce more case studies of reference system prototypes and device manufacturers need to enhance functionality without raising costs. A major part of the desired development is ease of integrating and developing specific applications in a common programming environment. Moreover, crucial infrastructure has to be built from IT service point of view in order to meet the requirement for reliability.

6 Conclusions

Wearable computing is a promising technology which is now beginning to enter markets such as for military applications and consumer goods, but also for industrial products and services. Technological maturity is closing to a state where practical industrial applications can be realized, providing a source for competitive advantage to pioneer companies. Until today, the price for full scale wearable computing including HMD-based augmented reality and hand gesture based interaction has been rather high, but low-cost simple applications are becoming affordable for use cases that do not require much conscious input from the user. On the other hand, wide-scale industrial service applications require a reliable infrastructure worthy of the expectations of industrial performance which is today seen as an uncertainty.

According to the results of our literature review, many authors identified the potential of wearable computing to gain efficiency improvements in industrial applications. This fact is proved by plenty of publications. However, there is still a lack of comprehensive case study results emphasizing the benefit of wearable computing in this area. Wearable computing is still a major risk in industrial service business because of its high cost and potentially minimal cost savings.

In a case study we identified several use cases that may benefit from the utilization of wearable devices. The Plant Isolation and Safety Assurance use cases were among them. The proposed wearable computing improvements to the plant isolation process provide several benefits, such as simplified equipment localization as well as reduced number of media-breaks due to the fact that sign-on/sign-off cards and ticket lists can be handled in electronically. Safety assurance can be improved by utilizing a low-cost safety suit that automates much of the mandatory environmental measurements. It also ensures that the right people are up to date to the health and status of the field engineer assigned to conduct a dangerous job, especially in confined spaces.

Future research will focus on implementation and evaluation of cost-efficiency of the proposed improvements in real world situations in a longitudinal study.

Acknowledgments The authors thank Barry Kleine, Ian Stokes, and Noel Wynd for their valuable feedback and support. We also thank Martin Naedele for supporting the project.

Markus Aleksy and Mikko J. Rissanen. Utilizing Wearable Computing in Industrial Service Applications. Journal of Ambient Intelligence and Humanized Computing (JAIHC), 2012. Springer. DOI: 10.1007/s12652-012-0114-2

Authors' version. The original publication is available at www.springerlink.com

References

Antifakos S, Michahelles F, Schiele B (2002) Proactive instructions for furniture assembly. In: Proceedings of the 4th international conference on ubiquitous computing (UbiComp '02), Springer, London, pp 351–360

Arduino (2011) http://www.arduino.cc/. Accessed 18 Nov 2011

Bahl P, Padmanabhan VN (2000) RADAR: an in-building RF-based user location and tracking system. In: Proceedings of the 19th international conference on computer communications (Info-com), IEEE, March 2000, vol 2. Tel Aviv, Israel, pp 775–784

Bajaber F, Awan I (2010) Energy efficient clustering protocol to enhance lifetime of wireless sensor network. J Ambient Intell Human Comput 1(4):239–248

Baudhuin ES (1996) Telemaintenance applications for the wearable PC. In: Proceedings of the 15th AIAA/IEEE digital avionics systems conference. IEEE, Atlanta, pp 407–413 Boger Y (2008) The 2008 HMD survey: are we there yet? White paper published by Sensics Inc. http://www.sensics.com/files/documents/2008SurveyResults.pdf. Accessed 23 Feb 2011

Bürgy C (1999) An interaction constraints model for mobile and wearable computer-aided engineering systems in industrial applications. Dissertation, Technical University of Darmstadt

Castro P, Chiu P, Kremenek T, Muntz RR (2001) A probabilistic room location service for wireless networked environments. In: Proceedings of the 3rd international conference on ubiquitous computing (UbiComp). Springer Verlag, Atlanta, pp 18–34

Crossan A, Williamson J, Brewster S, Murray-Smith R (2008) Wrist rotation for interaction in mobile contexts. Proceedings of the 10th international conference on human computer interaction with mobile devices and services (MobileHCI '08). ACM, NY, pp 435–438

Frey JH, Oishi SM (1995) How to conduct interviews by telephone and in person. SAGE, Thousand Oaks Computerzeitung (2005) Körpernahe Mobil-IT spart in Wartungsszenarien bis zu 50 Prozent Zeit ein. Computerzeitung 14, p 1

DeVaul R, Pentland A (2000) The memory glasses: towards a wearable, context aware, situation-appropriate reminder system. In: Proceedings of workshop on situated interaction in ubiquitous computing at CHI 2000, The Hague, 1–6 April 2000

Dickie C, Vertegaal R, Chen D, Fono D, Cheng D, Sohn C (2004) Augmenting and sharing memory with EyeBlog. In: Proceedings of CARPE 2004. ACM, NY, pp 105–109

Drugge M (2006) Interaction aspects of wearable computing for human communication. Dissertation, Luleå University of Technology

Enokido T, Aikebaier A, Takizawa M (2011) An extended power consumption-based algorithm for communication-based applications. J Ambient Intell Human Comput 2(4):263–270

Guardian Business Solutions (2000) Shipbuilder trims inspection and troubleshooting time by 70 %. http://www.gbsvoice.com/PDFs/Inspection.pdf. Accessed 21 Feb 2011

Hsu HH, Chen BK, Lin CY, Barolli L, Takizawa M (2011) Danger warning via fuzzy inference in an RFID-deployed environment. J Ambient Intell Human Comput 2(4):285–292

Ishii H, Bian Z, Fujino H, Sekiyama T, Nakai T, Okamoto A, Shimoda H, Izumi M, Kanehira Y, Morishita Y (2007) Augmented reality applications for nuclear power plant maintenance work. In: Proceedings of the international symposium on symbiotic nuclear power systems for 21st Century (ISSNP), Fukui Prefectural Wakasa Wan Energy Research Center

Kepper G (1999) Methoden der qualitativen Marktforschung. In: Herr A, Homburg C (eds) Marktforschung: Methoden Anwendungen—Praxisbeispiele, p 159–202

King T, Kopf S, Haenselmann T, Lubberger C, Effelsberg W (2006) COMPASS: A probabilistic indoor positioning system based on 802.11 and digital compasses. In: Proceedings of the first ACM international workshop on wireless network testbeds, experimental evaluation and characterization (WiNTECH 2006), September 2006, ACM, Los Angeles

Kortuem G (1996) Software architecture and wearable computing. Report, University of Oregon

Kortuem G, Segall Z (2003) Wearable communities: augmenting social networks with wearable computers. IEEE Pervasive Comput 2(1):71–78

Lyytinen K, Yoo Y (2002) Research commentary: the next wave of nomadic computing. Inf Syst Res 13(4):377–388

Mann S (1997) Wearable computing: a first step toward personal imaging. IEEE Comput 30(2):25–32

Mikalsen M, Paspallis N, Floch J, Papadopoulos GA, Ruiz PA (2006) Putting context in context: the role and design of context management in a mobility and adaptation enabling middleware. In: Proceedings of the international conference on mobile data management (MDM 2006)/international workshop on managing context information and semantics in mobile environments (MCISME), Nara, Japan, 9–13 May 2006. IEEE Computer Society, Washington, p 76

Nagashima, A (2006) Innovation initiatives toward year 2015. In: Proceedings of the 6th world congress on intelligent control and automation, IEEE, Dalian, China

Najjar LJ, Thompson JC, Ockerman JJ (1997) A wearable computer for quality assurance inspectors in a food processing plant. In: Proceedings of the first international symposium on wearable computers. IEEE Computer Society, Los Alamitos

Nicolai T, Sindt T, Kenn H, Reimerders J, Witt H (2006) Wearable computing for aircraft maintenance: Simplifying the user interface. In:

Proceedings of the 3rd international forum on applied wearable computing (IFAWC). VDE, Berlin

Nicolai T, Sindt T, Kenn H, Witt H (2005) Case study of wearable computing for aircraft maintenance. In: IFAWC-05: 2nd international forum on applied wearable computing. VDE/ITG, Berlin

Ohmura R, Naya F, Noma H, Kogure K (2006) B-pack: a bluetooth-based wearable sensing device for nursing activity recognition. In: Proceedings of the international symposium on wireless pervasive computing, 16–18 Jan 2006. IEEE, p 6

Olguin O, Gloor D, Pentland PA (2009) Wearable sensors for pervasive healthcare management. In: Proceedings of the 3rd international conference on pervasive computing technologies for healthcare. IEEE

OSHA (2011) http://www.osha.gov/SLTC/confinedspaces/. Accessed 18 Nov 2011

Priyantha NB, Chakraborty A, Balakrishnan H (2000) The cricket location-support system. In: Proceedings of the 6th annual international conference on mobile computing and networking (MobiCom 2000). ACM, Boston, pp 32–43

Roggen D, Forster K, Calatroni A, Holleczek T, Fang Y, Troster G, Lukowicz P, Pirkl G, Bannach D, Kunze K, Ferscha A, Holzmann C, Riener A, Chavarriaga R, del R Milla´n J (2009) Opportunity: towards opportunistic activity and context recognition systems. In: Proceedings of the 3rd IEEE WoWMoM workshop on autonomic and opportunistic communications, IEEE

Randell C (2005) Wearable computing: a review. Technical report CSTR-06-004, University of Bristol

Siegel J, Kraut RE, John BE, Carley KM (1995) An empirical study of collaborative wearable computer systems. In: Human factors in computing systems: CHI 95 conference companion, ACM, New York, pp 312–313

Siewiorek D, Smailagic A, Bass L, Siegel J, Martin R, Bennington B (1998) Adtranz: a mobile computing system for maintenance and collaboration. In: Proceedings of the second IEEE international symposium on wearable computers, IEEE Computer Society, Washington, pp 25–32

Shimoda H, Ishii H, Yamazaki Y, Wu W, Yoshikawa H (2004) A support system for water system isolation task in NPP by using augmented reality and RFID. In: Proceedings of the 6th international conference on nuclear thermal hydraulics, operations and safety (NUTHOS-6)

Stanford W (2002) Wearable computing goes live in industry. IEEE Pervasive Comput 1(4):14–19

Stein R, Ferrero S, Hetfield M, Quinn A, Krichever M (1998) Development of a commercially successful wearable data collection system. In: Proceedings of the second international symposium on wearable computers, IEEE Computer Society, Washington, pp 18–24

Stiefmeier T, Roggen D, Ogris G, Lukowicz P, Tro¨ster G (2008) Wearable activity tracking in car manufacturing. IEEE Pervasive Comput 7(2):42–50

van Megen F, Timm-Giel A, Salmre I, Go¨rg C (2006) Smart networking requests: supporting application development relying on network connectivity for wearable computers. In: Proceedings of the 3rd international forum for applied wearable computing, Bremen, Germany, pp 133–144

Want R, Hopper A, Falcao V, Gibbons J (1992) The active badge location system. ACM Trans Inf Syst 10(1):91–102

Ward K, Novick DG (2003) Hands-free documentation. In: Proceedings of the 21st annual international conference on documentation (SIGDOC ’03). ACM, New York, pp 147–154

Yin RK (2003) Case study research: Design and methods, 3rd edn. Sage Publications, Beverly Hills

Youssef M, Agrawala A (2005) The horus WLAN location determination system. In: Proceedings of the 3rd international conference on mobile systems, applications, and services (Mobisys), pp 205–218

Zieniewicz MJ, Johnson DC, Wong DC, Flatt JD (2002) The evolution of army wearable computers. IEEE Pervasive Comput 1(4):30–40