Notes of publication

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The attached document was published in March 2000 as my Sivilingeniør (≈ Master of Science) diploma thesis work at the Norwegian University of Science and Technology, Trondheim.

Writing the thesis was very exciting, and I met a lot of helpful academics, professionals and eccentrics as well as future colleagues while writing it, all of whom I thank for their contributions to my work. In particular, I met several very helpful and cooperative participants at the ICWC'99 in Stuttgart, Germany. I also greatly enjoyed the stimulating environments provided by Studio Apertura in Trondheim, Norway and Accenture Technology Labs in Sophia Antipolis, France.

The company formerly known as "Andersen Consulting" has later changed name to Accenture, and all references made to "Andersen Consulting" at the time now refer to Accenture.

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WEARABLE COMPUTERS

DEVELOPMENTS AND POSSIBILITIES

DIPLOMA THESIS

FOR

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"The digital road warrior's kit - laptop, cell phone, PDA, and pager - is just capable enough to bother you everywhere without necessarily helping you anywhere. It's absurd that each device is still on such poor speaking terms with the others. We walk around like pack horses saddled with information appliances. We should be in the saddle, not under it." [1]

– Nicholas Negroponte, MIT Media Lab, December 1995

"I don't think there's any question that the world of personal computers is evolving to a world of Internet access devices. More and more of those Internet access devices are in fact using wireless. I think we'll see wireless become the primary choice of high-speed connectivity." [2]

– Michael Capellas, CEO, Compaq, February 2000

"Oh, don't worry -- our comfortable PCs are hardly ready to retire, but it does seem increasingly likely that computing is expanding into decidedly non-desktop directions. And as this quickly moves from curiosity to mainstream, it will change all the rules -- again. This isn't a move that any of us want to ignore..." [3]

– Jeffrey Harrow, Compaq, March 2000

"The shoe computer seems like a joke, like Maxwell Smart. But go through those specs. A laptop: I've got to carry it, and a power supply, cables and adapters; I've got to sit down and open it up. The shoe: It's always with me, I don't have to look for it, I don't have to think about power supplies because it can be powered up from the friction of walking, I don't have to plug it in to things. I simply become the interface. All those specs make much more sense." [4]

- Neil Gershenfeld, MIT Media Lab, January 1999

Preface

This thesis work has been performed at Studio Apertura, Norwegian University of Science and Technology during the autumn of 1999 and winter of year 2000. The practical part of the thesis assignment was performed at Andersen Consulting Technology Park, Sophia Antipolis, France, in two periods of two weeks in July and October 1999.

One of the obstacles I've encountered in the process of doing research for this report, is that there is a lot of secrecy involved in the development of the commercial models of wearable computers. Researchers at for example MIT Media Lab widely distribute technical information and reports on their findings, while companies co-operating with for example IBM in the trials of their wearable computer prototypes are bound by strict confidentiality agreements. This has lead to problems getting enough information about the actual applications and the users' experiences. I have, though, despite the obstacles, received a lot of valuable feedback from users, researchers and companies. Thank you, all who have contributed.

I would also like to thank Per R. Stokke for initiating my contact with Martin Illsley at Andersen Consulting, and to thank Martin Illsley and Andersen Consulting for financing my participation at the ICWC'99 in Stuttgart, Germany, and for allowing me to visit (and for financing the visits to) their facilities in Sophia Antipolis, France, in July and October 1999. Thanks to Professor Per Morten Schiefloe for guiding me in the process of writing, and thanks to the others at Studio Apertura and Dragvoll Gård, giving informal feedback and inspiration in my work. Last but not least, I would like to thank all the people I've encountered in the process of preparations, research and writing: you have all given me inspiration and knowledge vital for the outcome of the work.

Trondheim, March 21st, 2000

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Anders Jacobsen

Abstract

This thesis deals with wearable computers. The main focus is on applications, but a technological overview and a documentation of an experimental implementation of a wearable computer system is presented.

The thesis presents the current state of the art in wearable computers hardware, commercial and known prototypes. A presentation of various components used for input, output and communication is also given.

Applications of wearable computers are described in three sections: some conceptual applications, concrete applications for various user groups and a presentation of eight known cases of wearable computer usage.

Potential social implications of introducing wearable computer technology are discussed in chapter 8, and a brief presentation of a technology presumed to be interacting and co-existing with wearable computers in the future, ubiquitous computing, is presented in chapter 9, and the differences and advantages of the two technologies are discussed.

In chapter 10 some recommendations for companies wishing to deploy wearable computer technology are given, and chapter 11 is the documentation of an experimental implementation of a wearable computer system for real-time capture of audio and video for knowledge management purposes.

Concluding the thesis, chapter 12 outlines and discusses the future of wearable computer technology.

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1 Introduction

Information technology has evolved rapidly the last decades. Moore's Law [5] states that computer capacity tends to double every 18-24 months, leading to exponential increase in computing power over brief periods of time. I have examined one particular direction in recent technology developments, namely mobile computing, and more specifically so-called wearable computers. I have discussed the technology, the products currently available and applications and challenges for organisations wishing to deploy such technology.

In this thesis, I aimed to do three things:

(i.) Present a background about wearable computers, describing current trends in the technology, manufacturers and information about the current market.

(ii.) Present current and possible applications for wearable computers, describing both general concepts and some known, existing installations. Discuss limitations and some potential dangers of wearable computers if widely used.

(iii.) Build and document a working prototype of a wearable computer application, specifically: a video capture-system with server backend analysing capabilities, enabling searching of captured video.

I worked on the latter objective during two visits to the Andersen Consulting Technology Park in Sophia Antipolis, France. I participated in building a wearable computer system based on commercially available components and the results of this work is documented in chapter 11 of the thesis.

I will treat objective (i.) and (ii.) by presenting and discussing information gathered from literature and from the Internet. I wish to answer the following questions:

- What kind of wearable computer technology is currently available, and what can we expect to see the next years?
- How can wearable computers improve the situation of various groups of workers?
- How will the introduction of wearable computer technology affect the users and their surroundings? Is privacy at stake?

As a conclusion, I will briefly discuss and draft the future developments of wearable computing on a short and long horizon.

2 What is a wearable computer?

Bass [6] suggests five characteristics of a wearable computer:

(i.) It may be used while the wearer is in motion.

(ii.) It may be used while one or both hands are free, or occupied with other tasks.

(iii.) It exists within the corporeal envelope of the user, i.e., it should be not merely attached to the body but becomes an integral part of the person's clothing.

(iv.) It must allow the user to maintain control.

(v.) It must exhibit constancy, in the sense that it should be constantly available.

Professor Steve Mann provides a thorough definition of wearable computing and related concepts in [7]: The most significant difference between a wearable computer and an ordinary desktop or portable PC is the fact that if you *wear* it - it's continuously available: it’s always on, always running. To retrieve or record information on a portable PC or a PDA, the device needs to be opened and turned on first, while a wearable computer can record or provide the information right away - even voice controlled. It might not seem to be a large difference, but the impact can be significant: There are many situations in which one would hesitate to start up one's portable PC just to perform some small tasks, and there are also situations where a portable would not be practical. For example when there is a lack of space available or because the operator is continuously on the move, or uses both hands, a wearable could provide a platform better suited for the use than traditional computers.

The wearable computer also enables new, previously unseen, possibilities using head-mounted displays:

- Augmented reality (the real-time addition of information to one's view; like instructions for performing tasks, “name-tagging” of persons and/or items, additional sensor-information (you can get “night-vision” or thermal vision) etc),
- Mediated reality (addition of elements to, removal of elements from or modification of elements in one's view)

Or for example:

- Truly photographic memory (computer can use a video capture device, store one's activities and then, either using "intelligent agents" or by manual request, retrieve video and/or audio from the wearable computer's hard drive or a server).

The above mentioned technologies will be explained further later in this text.

Another significant aspect of wearable computing is that it can be operated while the operator's main focus is on something else (e.g. the wearable can perform actions while the user is walking or moving around – there is no need to sit down, like with a laptop).

Rhodes [8] concluded: "Wearable computers are by their nature highly portable, but their main distinguishing feature is that they are designed to be usable at any time with the minimum amount of cost or distraction from the wearer's primary task."

3 Background / a brief history of wearable computers

Statisticians Ed Thorp and Claude Shannon presented the first known "wearable computer" device in 1966. They had invented a cigarette-pack-sized analogue computer with four buttons used by an assistant for inputting the speed of a roulette wheel. The computer then sent tones via radio to a bettor's hearing aid. The system had been invented in 1961 but was first mentioned in a publication by E. Thorp in 1966 [9], and further details were revealed in 1969 [10].

In 1978 Eudaemonic Enterprises, a company founded by a group of physicists and friends, invented a digital wearable computer in a shoe, also used for predicting roulette wheels. This is the only known roulette machine of the time to show a statistical profit on a gambling run [11]. According to one of the inventors, Thomas A. Bass, their "wearable" gave the bettor up to a 44% advantage over the casinos [12], i.e. for every dollar they played, they could expect a return of as much as $1.44.

Steve Mann [13], the pioneer of modern wearable computing, invented his first wearable computer in 1981. He used it to control camera-equipment, flashes and other photographic equipment.

Gerald Maguire and John Ioannidis presented the first prototype of a functional wearable computer with "ordinary" desktop computer-features in 1990 [14]. Named "the Student Electronic Notebook", it consisted of a diskless Toshiba notebook computer, a "PrivateEye" head mounted display, and used radio links to provide network services.

In 1994, Steve Mann starts continually transmitting images from his wearable computer to a web-server, allowing "the world" to follow his moves. This soon became one of the most visited web pages in the early history of the WWW.

Image: a series of images of Steve Mann's wearable computer inventions (Source: [13])

4 Current trends in the technology

4.1 Hardware

It is customary for a wearable to be equipped with a head-mounted display (HMD) of some kind, allowing it to give the user information without needing to move. The most used input devices are a keyboard (or a "twiddler" [15]) and/or a microphone (for voice control). Other devices, like video cameras, GPS, or any other PCMCIA or USB devices, are also possible. The commercially available systems run any Microsoft Windows or Linux operating system, and are therefore familiar for most users. However, so far product sales have not reached great heights. Gartner Group listed wearable computers as one of the top 10 technologies to look out for in 1999, but projected sales to remain moderate the next 3-5 years as the technology matures.

The general trend appears to be that the elements of the computer keeps getting smaller, the battery-life longer, and the displays better.

4.1.1 Battery-life

There are several technological approaches running on improving battery-life. One of the approaches is lowering power-consumption by the processor and other components. Intel [16] and AMD [17] continually improving its processors by allowing "economy"-modes during run-time [18, 19]. Their new competitor Transmeta [20] is also developing innovative solutions to the battery-problem. They recently launched a processor called Crusoe [21], and claim it improves the battery life four to five times compared to standard chips [22].

Another approach to solving the problem of limited battery power carried by the user is improved battery technology [23] or power-generation by the user himself [24]. The latter concept is being developed in a longer perspective, and there are no commercial products available.

4.2 Manufacturers of wearable computer systems

There are several commercially available systems on the market, and a wide variety of "self built" machines, of which the most famous belongs to Steve Mann. Among the commercial systems, Xybernaut Corporation [25] is playing a leading role, with its current top model running a Pentium MMX 233 MHz processor and thereby having approximately the same CPU-power as an ordinary desktop or laptop PC had a few years back. IBM and other commercial players have only shown prototypes.

Manufacturers with serial production:

- Xybernaut Corporation, VA, USA, manufactures the “Xybernaut Mobile Assistant” [26], available in version IV. The Xybernaut MA IV is probably currently the most used commercial wearable computer available, running an Intel Pentium MMX 233MHz processor and capable of running all major operating systems.
- ViA Inc. [27], MN, USA, manufactures the “ViA II PC” [28], a flexible wearable computer running a standard Intel Pentium 166 MHz Processor. The ViA unit is slightly less powerful than the than a Xybernaut MA IV, but it appears smaller and lighter.
- Interactive Solutions [29], FL, USA, manufactures the “Mentis multimedia wearable computer”, a modular wearable computer based on an Intel Pentium MMX processor. Optional multimedia plug-ins allows for e.g. full-screen live-motion video.
- Genesis Technology Group [30], VA, USA, manufactures the “Cyberknight Voice Activated Head Mounted Computer” [31] but doesn’t supply much information about the unit’s computing power except that it is very flexible regarding input- and output options.

Known commercial prototypes per March 2000:

- AIMS “WetPC” [32], a waterproof wearable computer for divers being developed by the Australian Institute of Marine Science
- IBM Wearable Computer [33, 34]
- Olympus and IBM Japan Wearable Computer [35]

Some prototypes and/or experimental units produced by independent researchers

- MIT “Lizzy” [36] is the “default” wearable computer of the MIT Media Lab “cyborgs”, and a full component listing and assembly instructions are available on the web-pages.
- Carnegie Mellon University “VuMan” [37]
- University of Toronto “Half-QWERTY” wearable [38]
- Steve Mann’s WearComp7
- “TurboTortoise” [39]

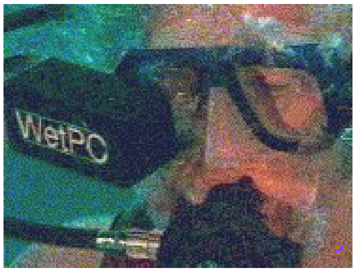

Image: "WetPC" (Source: [32])

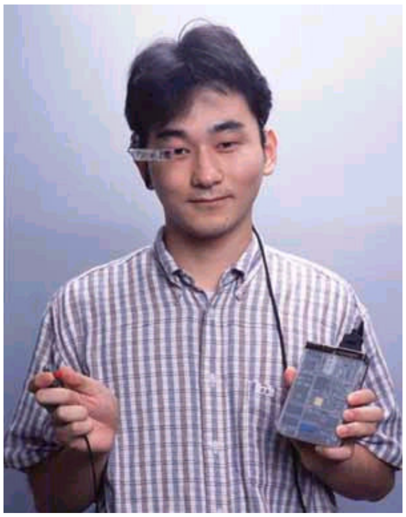

Image: IBM's wearable computer prototype (Source: IBM Japan)

Image: Steve Mann wearing his "WearComp7" (Source: [13])

Image: Steve Mann "under the hood" (Source: [40])

4.3 Available components for wearable computers

4.3.1 Input

4.3.1.1 Software

4.3.1.1.1 Voice recognition

This category of software uses pattern recognition methods to map an input speech waveform into corresponding text or a discrete output [41]. Commercially available speech systems include

- IBM ViaVoice [42]
- Dragon Naturally Speaking [43]
- Lernout & Hauspie Speech Products [44]

For applications in which speech commands are used to sequence through menu items, isolated or connected word systems suffice. The above mentioned systems are also capable of recognising continuous speech, useful for dictation or filling out information fields, report forms et cetera.

4.3.1.2 Hardware

4.3.1.2.1 Keyboards and related devices

- Twiddler [15], a keyboard-device operated by one hand.
- Other miniature versions of standard "QWERTY"-keyboards.

- "Thumbing" [45, 46] – using a one hand glove to recognise finger-movement patterns.
- "FingeRing" [47] – using ring shapes sensors on each finger to record finger-tip typing action
- "WristCam" [48] – processing of the images from a camera attached to a user's hand is used to yield finger movement information.

4.3.1.2.2 Eye-based control

According to Calhoun and McMillan [41], harnessing the direction of eye gaze promises to be a very natural and efficient control interface for applications in which the operator views a display during control operations. There are several methods to do these measurements [49], but no commercial systems available to date.

4.3.2 Output

4.3.2.1 Visual

Head Mounted Displays were first experimented with by Ivan E. Sutherland in the early nineteen sixties, displaying images for the pilots from servo-controlled cameras on helicopters [50]. In an early project at Bell Helicopter Company, the head-mounted display was coupled with an infrared camera that would give military helicopter pilots the ability to land at night in rough terrain. An infrared camera, which moved as the pilot's head moved, was mounted on the bottom of a helicopter. The pilot's field of view was that of the camera.

Today, there are several variants of head mounted displays available, using different techniques, but the most common are a small projector mounted on the side of the head, projecting into a lens or mirror in front of the eye, or a translucent LCD-display put in front of the eye itself:

- SONY Glasstron [51, 52]
- MicroOptical Corporation's Integrated Eyeglass Display and ClipOn Display [53, 54]
- The MicroDisplay Corporation [55]
- Microvision, Inc. [56]
- Seattle Sight Systems [57]
- Liquid Image Corporation [58, 59]

- Kopin CyberDisplay™ [60, 61]
- Albatech Eyeglass mounted Personal Monitor [62]
- Displaytech Display Panels [63, 64]

Image: MicroOptical Corporation's Integrated Eyeglass Display (source: [65])

4.3.2.2 Audible

A wearable computer can give output by reading results of queries aloud through a speaker or a headphone. Combined with voice recognition-technology as described in chapter 4.3.1.1.1, a user can have a command-based dialogue with his computer, if that is the interface best suited for the user's needs. An example of a situation where this would be feasible could be while driving a car, or doing other tasks where one cannot look away.

4.3.3 Wireless communication

4.3.3.1 Infrared

Infrared communication using the IrDA-standard between two computers is possible. The drawback is that infrared communication demands a free line-of-sight and is only useful within a few metres' distance. However, it can successfully be used to transmit files between two computer users, or for example to wirelessly print through an IR-enabled printer and similar uses. Infrared can also be used by "beacons" to transmit small packets of data signalling location or similar properties (see also chapter 7.1.2).

4.3.3.2 Cellular phones

Cellular phones can easily, though currently not cost-effectively, be used to bring a wearable computer online. Below are some information about the most widely used digital technology (GSM) and some technologies in the horizon (GPRS and UMTS).

4.3.3.2.1 GSM

GSM (Global System for Mobile communication) is a digital cell-phone network expanding rapidly throughout the world. According to numbers from International Telecommunication Union [66] and Yankee Group [67] presented in Wired 8.03 (March 2000), GSM has approximately 240,000,000 users world-wide, of which the vast majority is in Europe [68]. GSM provides a 9600 bit/s data-rate, which is suitable for low-volume communications like email and chat, but less suitable for transferring web pages, images or large files.

4.3.3.2.2 GPRS

General Packet Radio Service (GPRS) "is a packet-based wireless communication service that, when available in 2000, promises data rates from 56 up to 114 Kbps and continuous connection to the Internet for mobile phone and computer users. The higher data rates will allow users to take part in videoconferences and interact with multimedia Web sites and similar applications using mobile handheld devices as well as notebook computers. GPRS is based on Global System for Mobile (GSM) communication and will complement existing services such circuit-switched cellular phone connections and the Short Message Service (SMS)." [69]

4.3.3.2.3 UMTS

"UMTS (Universal Mobile Telecommunications System) is a so-called "third-generation (3G)," broadband, packet-based transmission of text, digitized voice, video, and multimedia at data rates up to and possibly higher than 2 megabits per second (Mbps)." UMTS offers a consistent set of services to mobile computer and phone users no matter where they are located in the world. "Based on the Global System for Mobile (GSM) communication standard, UMTS, endorsed by major standards bodies and manufacturers, is the planned standard for mobile users around the world by 2002. Once UMTS is fully implemented, computer and phone users can be constantly attached to the Internet as they travel and, as they roam, have the same set of capabilities no matter where they travel. Users will have access through a combination of terrestrial wireless and satellite transmissions. Until UMTS is fully implemented, users can have multi-mode devices that switch to the currently available technology (such as GSM 900 and 1800) where UMTS is not yet available." [70]

4.3.3.3 Microwave

4.3.3.3.1 Terrestrial microwave (wireless LANs)

In-house or on a geographically limited area, it is possible to set up a “Wireless LAN” using radio transmissions in the microwave spectrum. The typical frequency used in wireless LAN products today is 2.4 GHz, and data-rates in commercial products vary from 2-11 Mbps. The top models are comparable to the speeds achieved for ordinary desktop PCs in a wired LAN (typically 10 or sometimes 100 Mbps), and will provide more than good enough coverage for wearable computer users as long as they remain within the boundaries of coverage.

4.3.3.3.2 Satellite Microwave

Satellite telecommunication services are and are increasingly becoming available, but are not likely to have large impact on wearable computer utilisation the next years due to very high cost, handset/antennae-size and low data-rates. ICO Global Communications [71], Iridium [72], Globalstar [73] and Asia Cellular Satellite [74] are all implementing or have implemented satellite-based telephony.

5 Market

The market for wearable computers is currently limited. According to a study by Gartner Group in March 1998, “Fewer than 100 organisations, many from the military, have bought evaluation units for pilot studies into the effectiveness of the technology. Many of these evaluations are now complete, and the level of roll out during the next year will be a good indication of whether the market is ready to deploy at the current level of cost and display quality. If so, adoption will be slow for the next three to five years, with rapidly-evolving products and a somewhat unstable vendor space, but will build to be a mainstream technology for maintenance and other mobile industrial applications by 2006.” [75]

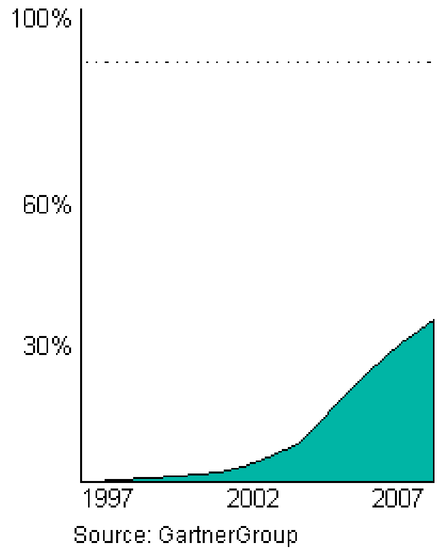

Figure: Percentage of Fortune 1000 Enterprises Adopting Wearable Computing (source: GartnerGroup, [75])

In a presentation given to the ICWC'99 conference in Stuttgart, Germany, Edward G. Newman, president and CEO of Xybernaut Corporation showed predictions by the Yankee Group regarding mobility of the workforce. The trend has been approximately exponential growth of cellular subscribers since 1986, and they predicted 400 million cellular subscribers by 2002. Mr. Newman predicted a similar growth for wearable computer devices further into the future. The Yankee Group has also estimated that 33% of large US corporations will provide service and sales personnel with wireless mobile data access by 2000, with a potential of 21.3 million users by 2002.

In another Gartner Group report, "Computing 2003 and Beyond: Contextual and Spontaneous" [76], the author suggests that we will still be in "The Network Computing Era" until year-end 2001. The Network Computing Era is defined by the main characteristic of "the need for connectivity to the network", with the side-effect of the constant connectivity being a "highly interrupt-driven work force, as workers try to keep up with the barrage of E-mail and real-time information feeds." The author predicts a shift to "The Contextual Computing Era" beginning around 2002, and finally a widespread use of wearable computers in "The Spontaneous Computing Era", beginning around 2007. The Spontaneous Computing Era relies on low-cost, universally accessible wireless communication. This capability will provide "anytime, anyplace access to information and messaging through highly portable or wearable systems". The capability "will be enhanced by the ability to access information sources through speech dialogues, which will blur the distinction between automated telephony and computer-based information devices".

In his presentation at the ICWC'99, Maurizio Gasperi, Business Development Manager of Hewlett Packard Germany identified HP's top ten potential markets for wearable computers [77]. They included:

- Heavy Equipment Manufacturers
- High Technology Manufacturers
- Transportation/Distribution
- Insurance/Health Care
- Securities
- Telecommunications
- Hazardous Processes
- Retail/Wholesale
- Entertainment
- Food & Beverage

6 Technologies for collaboration

Dr. Walter Hehl from the IBM Industry Solutions Labs in Stuttgart and Zürich puts wearables in the context of collaboration [78]: In a company in which computer network technology is widely used for collaboration, the completeness of the Network is important for a successful outcome. There are gaps in the electronic network, for example paper and voice communication, but wearables can help completing the Network.

Table: Asynchronous and Synchronous Collaboration (Source: Hehl, [78])

		Location	
		Same place	Different place
Time	Asynchronous	Same Place, Different time, e.g. Folders, Archive	Different Place, Different Time, e.g. email, Lotus Notes
	Synchronous	Same Place, Same Time, e.g. traditional meeting	Different Place, Same Time, Classical: Telephone, Videoconferencing **New: Wearable Computers**

Computer technology, and in this context especially wearable computer technology can provide awareness ("who is available to communicate with?"), means for communication (conversation) and an opportunity to share objects in a blackboard-like fashion. Success factors for such technology are simplicity, coherence, low cost, scalability and open communication standards, according to Hehl.

IBM's "Sametime Vision" contains elements of the above features, in synchronous and asynchronous modes:

Table: Asynchronous and Synchronous Collaboration, IBM's "Sametime Vision" (Source: Hehl, [78])

	Awareness	Conversation	Shared Objects
Synchronous	People listings, based on / in context with location and documents/projects ("Who are working on the same things as me right now?")	Chat / Instant Messaging using text, audio and/or video	Objects, white-board application
Asynchronous	"New" and "unread"-flags on shared items ("Who has changed or contributed anything since I last visited these documents?")	Email, bulletin boards, discussion databases	Archived documents, attachments, hyperlinks

Prof. Dr. Eva Kühn from Tecco Coordination Systems [79] has patented a "Virtual Shared Memory" middleware-technology for wearable collaboration called CORSO [80, 81]. A CORSO implementation called "Flow&Co" is a universal add-on for existing workflow management systems (WFMS), supporting collaborative patterns between the single users, extending the original WFMS-systems with mobility and collaboration.

Advanced, multi-user and three dimensional video conferencing utilities are being developed [82], using Augmented Reality (read more in chapter 7.1.3) . See also Feiner's statements on the future of mobile collaboration in chapter 8.1.3.

7 Existing and potential applications of wearable computing

There are lots of ways wearable computers can enhance both work and everyday life of individuals, and I'll try to introduce a few basic concepts at first, then present some actual, commercially used applications and finally some examples from specific companies.

7.1 Concepts

7.1.1 Interactive Assistant

Intelligent agents are known for example on the World Wide Web, as they can aid a user in performing better searches (or even do searching in the background, presenting interesting information to the user as it becomes available). In combination with a wearable computer, this can have significant impact on the way we work in general: contextually aware intelligent agents can feed us with real-time information or personal messages as the user is working, or even as he does other things, like sitting on a bus or eating lunch.

Agents can act on the user's behalf, communicating with the Internet or other wearable users, as described by Kortuem et al [83, 84]. In the communities they describe, agents running on the individuals' wearable computers act on their owners' behalf, negotiation and co-operating with each other during encounters. The agents have several properties, including being goal-oriented, opportunistic (act in their owners' best interest), predictable and rational. Agents can for example make deals both users gain from: if two delivery service drivers, not necessarily from the same company, meet briefly by chance, their agents can exchange information about routes and suggest and negotiate trades if they have areas in common. ("If you take this parcel to location A, I'll go to location B with that parcel for you"). The authors also outline the possible problem of deceptive / lying agents, but describe protocol strategies to make deception sub optimal.

Researcher Bradley Rhodes at MIT Media Lab is developing a "remembrance agent" [8, 85, 86] which continuously monitors the user's activities (e.g. writing documents, reading/writing email et cetera) and suggests relevant documents from previous activities. For example, if the user is writing an email to a company regarding employment, the Remembrance Agent can suggest documents related to previous job searching, a stored résumé and for example notes the user has made about employees he has met from the company. Andersen Consulting's "Awareness Machine" [87] has similar capabilities and Jason Pascoe from University of Kent at Canterbury has described and demonstrated a "Contextual Information Service" [88] that presents notes related to a user's context, taking account of, among other things, location (GPS-based).

With appropriate development, user-interfaces will monitor the user's actions and act appropriately (e.g. "When I am talking, you are listening" – A wearable should not interrupt its user.) Also, the wearable should be able to present the information in a way that is appropriate for the user: before driving, it might be interesting to se a map of the distance to be driven, but while driving, it will be preferable if the computers either reads aloud directions ("turn left at the next crossroads") or discreetly shows arrows with the directions. Ultimately, the wearable will perform the non-trivial task of providing the most relevant information in the right way at the right place and at the right time.

7.1.2 Tourist assistance / location awareness

If added a location-sensor device like a GPS (Global Positioning System)-sensor, the user of a wearable computer can configure the device to provide detailed tourist/location information [89, 90], made available by for example local authorities or external websites. Researchers at Columbia University Computer Graphics and User Interfaces Lab have built "The Touring Machine" [91, 92] - a wearable computer with GPS-capabilities, to provide a campus information system. Infrared transmitter-units may aid a wearable computer identify its location. More CPU-intensively, it is possible to analyse the input from a video camera, allowing location recognition from previous training [93]. If a small IR "beacon"-unit is located at the entrance of different rooms, the wearable computer may become location aware without the need of a GPS-receiver or video signal analysis [94, 95]. There are also other, various methods for position tracking, e.g. 3D accelerometers or 3D magnetometers [96].

Extending the capabilities, the user can also exchange messages with fellow travellers through "virtual bulletin boards" or "virtual information towers", located in the "virtual space" but tied to physical co-ordinates in the real world [97]. A user could even add spatially located reminders to himself/herself or to a friend/colleague/spouse – for example a shopping list that would appear on the user's display when entering the grocery store.

7.1.3 Augmented Reality

Augmented Reality (AR) is of particular interest for wearable computers. Interpreting the signals from a head-mounted camera, the wearable computer unit can superimpose assembly-instructions or other information from the manuals into the user's view through the head-mounted display. This allows a user to work more efficiently on tasks that are so complex that they require frequent look-ups in manuals or instructions. Boeing (see specific information in chapter 7.3.3) is experimenting with wearable computers with an AR set-up.

The use of Augmented Reality requires recognisable landmarks or an exact positioning and direction-monitoring device. Recognition from a 3D-model is demanding on CPU-power, but possible to do. The users of AR systems expect exact and up-to-date information, and this requires updated databases of information – for example connection to ERP-databases.

A different AR-application is a 3D augmented reality videoconferencing tool, as described by Kato et al [82]. An example of the use of such a tool might look like this:

Image: Remote user representation in an augmented reality videoconference (Source: Kato et al [82]).

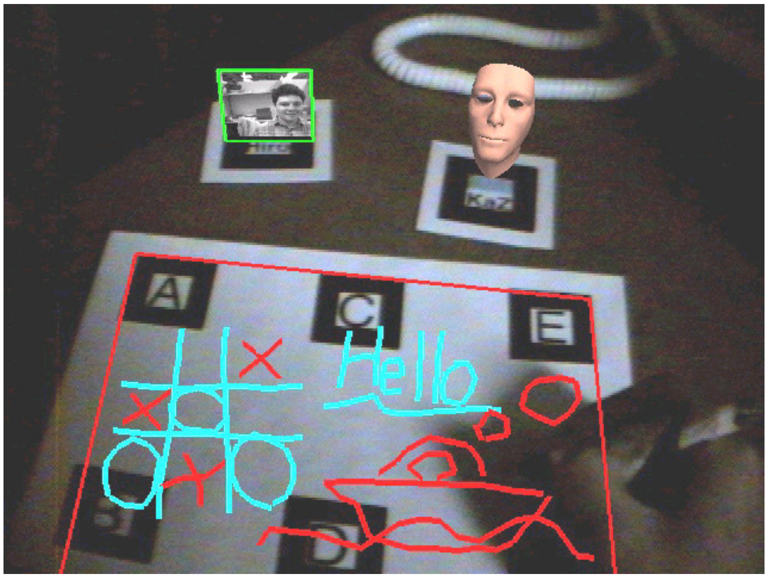

Image: Shared whiteboard in an augmented reality videoconference (Source: Kato et al [82]).

7.1.4 Mediated Reality

Mediated Reality is a concept introduced by Professor Steve Mann. The concept is the ability to alter one's perspective and sensory input. He described "living with" this technology in an article in Technology Review, May/June 1999:

> "I have melded technology with my person and achieved a higher state of awareness than would otherwise be possible. I see the world as images imprinted onto my retina by rays of light controlled by several computers, which in turn are controlled by cameras concealed inside my glasses.
>
> Every morning I decide how I will see the world that day. Sometimes I give myself eyes in the back of my head. Other days I add a sixth sense, such as the ability to feel objects at a distance. If I'm going to ride my bicycle, I'll want to feel the cars and trucks pressing against my back, even when they are a few hundred feet away.
>
> Things appear different to me than they do to other people. I see some items as hyperobjects that I can click on and bring to life. I can choose stroboscopic vision to freeze the motion of rotating automobile tires and see how many bolts are on the wheels of a car going over 60 miles per hour, as if it were motionless. I can block out the view of particular objects—sparing me the distraction, for example, of the vast sea of advertising around me." [98]

The technology Professor Mann uses is highly experimental and self-developed, but some of the technologies he uses can become realities for ordinary users in the future.

7.2 Applications

7.2.1 Information collection

Data recording and data retrieval through a wireless connection is possible already today in commercially available systems, and they have already been used successfully in data recording in urban areas (geophysical data [99], street sign inventory data [100], infrastructure maintenance [101] etc.) Dàtria Systems Inc. [102], a software manufacturer, supplies a voice-controlled database solution well suited for mobile data-collection applications.

7.2.2 Training

Wearable computers can provide task specific information, training and assistance at the work site when most needed. Sending personnel to external training classes may be cost ineffective, if effective just-in-time training can be provided on the spot, shifting the focus from training/teaching to supporting/enabling individuals to learn while completing work. Integrating the many existing educational/support technologies into one unified system directly tied to the tools used in performing the job will be a challenge, but will truly demonstrate the power of these systems.

7.2.3 Remote Experience

In 1999, the French shopping centre Le Printemps launched a service called "Webcamer" [103] where shop assistants equipped with a computer, a cellular phone, Rollerblades and a digital video camera will give Printemps' web-customers a feeling of shopping in the real store in Paris. The "Webcamer"-assistant will go to the desired product and show it to the on-line customer.

Image: "Webcamer" shopping assistant (Source: Webcamer.com, [103])

7.2.4 Maintenance / inspection worker

There are many applications of a wearable computer for inspection and maintenance work. Inspectors of factories, vehicles and other equipment can log data, store images or contact experts. Maintenance and plant operation applications are characterised by a large volume of information that varies slowly over time. For example, even simple aircraft will have over 100,000 manual pages [104]. However, due to operational changes and upgrades, half of these pages are made obsolete every six months. Rather than distributing CD-ROMs for each maintenance person and running the risk of a maintenance procedure being performed based on outdated information, maintenance facilities usually maintain a centralised database to which maintenance personnel make inquiries for the relevant manual sections on demand. According to Carnegie-Mellon University researchers, a typical request consists of approximately ten pages of text and schematic drawings. Changes to the centralised information base can occur on a weekly basis. Making this information available wirelessly to wearable computers can save time and money. The wearable computer can also provide the worker with access to enterprise resource planning (ERP) systems like SAP [105], enabling a more effective internal organising of the workforce. The investment in wearable units would be small compared to the investment in an ERP-system. The most updated manuals and for example lists of spare parts or maintenance history can be accessed instantly, eliminating numerous walks and allowing the worker to stay in position and to keep the hands and eyes on the machine. Checklists and forms may be filled in by voice on the spot, or even on the move to the next assignment. When in doubt, expert- or peer advice can be made available through video conferencing. Information can also be gathered by searching corporate knowledge databases or from the Internet.

7.2.5 Knowledge worker

> "A knowledge worker is anyone who works for a living at the tasks of developing or using knowledge. For example, a knowledge worker might be someone who works at any of the tasks of planning, acquiring, searching, analysing, organising, storing, programming, distributing, marketing, or otherwise contributing to the transformation and commerce of information and those (often the same people) who work at using the knowledge so produced. A term dating from about 1996, the knowledge worker includes those in the information technology fields, such as programmers, systems analysts, technical writers, academic professionals, researchers, and so forth. The term is also frequently used to include people outside of information technology, such as lawyers, teachers, scientists of all kinds, and also students of all kinds." [106]

Peter F. Drucker coined the term Knowledge Worker in 1959, observing and forecasting the tendency of a shift from a focus on manual labour to jobs that require formal education [107].

> "Knowledge workers will not be the majority in the knowledge society, but in many if not most developed societies they will be the largest single population and work-force group. And even where outnumbered by other groups, knowledge workers will give the emerging knowledge society its character, its leadership, its social profile. They may not be the ruling class of the knowledge society, but they are already its leading class. And in their characteristics, social position, values, and expectations, they differ fundamentally from any group in history that has ever occupied the leading position.
>
> In the first place, knowledge workers gain access to jobs and social position through formal education. A great deal of knowledge work requires highly developed manual skill and involves substantial work with one's hands. An extreme example is neurosurgery. The neurosurgeon's performance capacity rests on formal education and theoretical knowledge. An absence of manual skill disqualifies one for work as a neurosurgeon. But manual skill alone, no matter how advanced, will never enable anyone to be a neurosurgeon. The education that is required for neurosurgery and other kinds of knowledge work can be acquired only through formal schooling. It cannot be acquired through apprenticeship."
>
> "In the knowledge society, for the first time in history, the possibility of leadership will be open to all. Also, the possibility of acquiring knowledge will no longer depend on obtaining a prescribed education at a given age. Learning will become the tool of the individual--available to him or her at any age--if only because so much skill and knowledge can be acquired by means of the new learning technologies." [107]

A knowledge worker deals mainly with information, gathering it, using it and/or giving it out. Being adaptive when it comes to obtaining new knowledge is essential, and continued education characterises a knowledge worker. There is a tendency that more and more people will be knowledge workers in the future, and they include anyone from business executives to air stewardesses, insurance inspectors and helpdesk assistants.

Drucker [107] points out that the organisations of the future will become increasingly dependent of the knowledge workers. He also concludes that the workers themselves own the tools of production, as the companies' physical possessions become worthless unless workers with knowledge of their functions and appropriate use man them.

Only the imagination can limit the potential applications of wearable computers for knowledge workers: "everything" from transcription of conversations and meetings, to intelligent agents feeding pieces of relevant information to the user is possible. Edward Younker from the Gartner Group suggests that another implication of spontaneous computing (made possible by wearable devices) may be that knowledge workers will spend more time in meetings, because live interaction continues to be one of the hardest elements of the work environment to simulate through technology. "The secondary access and creation tasks could be achieved as part of the meeting workflow rather than as separate dedicated activities. Some users may find that spontaneous computing further blurs the lines between work and leisure time, while others will strive to maintain a firm distinction." [76]

The core potentials of the wearable computer for a knowledge worker are the capabilities of communication and knowledge/data mining. Using wearables, capturing knowledge can happen along with recording the relevant context and the contribution to knowledge management systems can become a natural part of the line of work, instead of an extra burden at the end of projects. Agents continuously accessing relevant information from corporate knowledge management systems or external databases and websites, using technologies like the "Awareness Machine" [87] or the "Remembrance Agent" [8], can improve the performance of the workers and provide continuous education.

An additional feature for the business traveller is the ability to work in complete privacy, as the head mounted screen is only possible to read for one person, unlike the display of a regular laptop PC. The "virtual screen", projected in the user's glasses or similar, may also appear larger than a laptop PC's screen for the user. (SONY Glasstron glasses, for example, provide the feeling of viewing up to a 52-inch screen at an approximately 6½ feet distance). J. Fenn from the Gartner Group believes this feature (larger screens) will drive the general-purpose adaptation of wearables [108].

7.2.6 Medical

Health care workers can interface with diagnostic equipment, voice-annotate examinations and transfer medical information while leaving their hands free to physically assist the patient. Doctors and surgeons have or will have the possibility to create digitised records through dictation while monitoring the patient's vital statistics, viewing patient records or even looking at high resolution digital X-ray images in the head mounted display.

Dr. rer. pol. Wolfgang Röckelein from the Universitätsklinikum Regensburg has presented an ongoing research project to create "The NOAH-Vest" [109]. NOAH, short for Notfall-Organisations- und ArbeitsHilfe (Emergency Organisation and Administration Aid), aims to address two weak points in an otherwise excellent German emergency care system: communication and documentation. Using Xybernaut components, they have fitted an emergency physician's vest with a wearable computer, touch-screen and wireless communication capabilities.

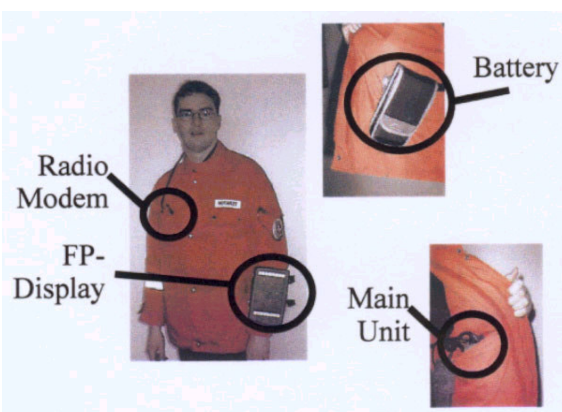

Image: The NOAH-vest (source: Xybernaut promotional material)

When an ambulance is dispatched, the emergency physician will get data from the distress call available on his screen (mounted on his arm), giving an initial preparation on what to expect. On-scene and/or during the return to the hospital, the physician uses a visual interface on the touch-screen to feed diagnostic information back to the hospital; more than doubling the available time for preparation, by making it a "parallel process":

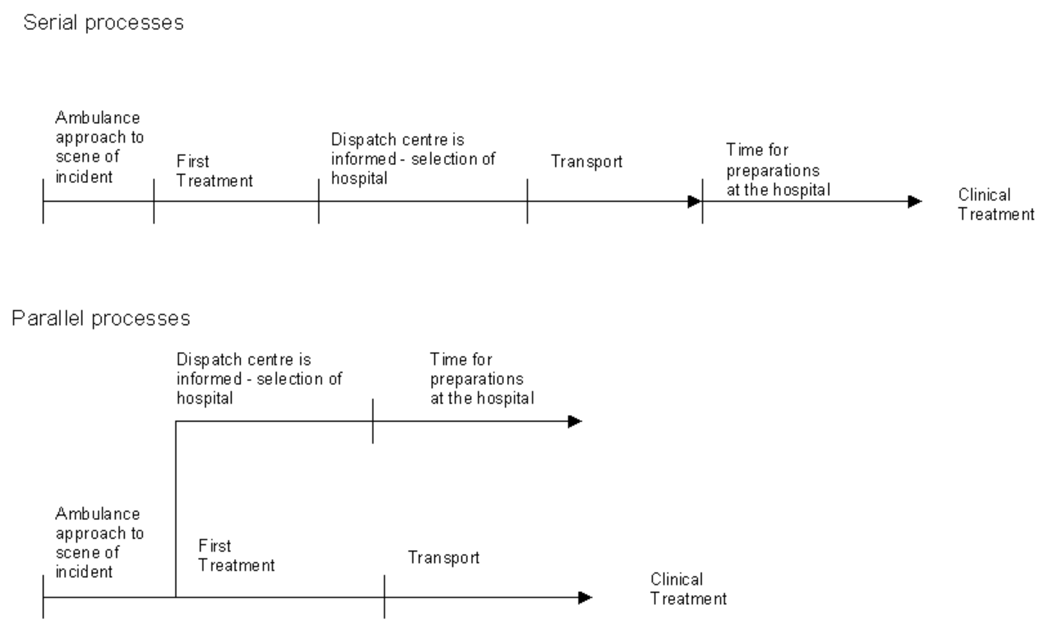

Figure: Improvement in hospital preparation time by using wearable computers in emergency medical treatment. ("Parallel process" illustration redrawn from [109])

Outlined future requirements/developments for the NOAH-system includes additional interfaces (vital signs, GPS etc.), touch-screen readable under all conditions (from direct sunlight to complete darkness), battery-pack with duration of up to 8 hours, docking stations for cars and airborne transport, speech recognition, video-input and an improved communication unit. Other researchers are developing similar systems for medical applications, including the Paramedic protocol and patient reporting computer, "P^3CO", described by Baber et al [110, 111].

At the "Future Lab" at Norwegian National Centre of Telemedicine [112] in Tromsø, researchers are developing a concept they call "CyberNina" [113]. CyberNina represents the healthcare worker of the future, not only focusing on medical doctors, but also on nurses and other personnel. Researchers have identified some core areas of application to focus on, including emergency physicians, surgeons (Augmented Reality-applications), doctors making the rounds and X-ray-technicians. Other medical personnel, including bio-engineers and doctors on call have shown interest in the concept of mobile solutions, but have expressed preference for a solution with for example small hand-held computers or personal digital assistants (PDAs) rather than the more sophisticated wearable computers. The research centre is also working on developing a mobile unit for telemedicine, to be used on for example boats, in disaster areas et cetera.

Turning the perspective around, a patient under medical observation can go on living his or her life equipped with a wearable computer, while the computer monitors vital statistics and regularly sends feedback and measurements back to the hospital. The wearable could also warn its user if he or she is living too stressfully (with a heart-rate monitor), breaking the diet (for diabetics, a small blood-sugar-monitor could be fitted to interface with the wearable) or experiencing symptoms of some illness the wearable is configured to look out for. Wearable computers also have applications for the disabled, see chapter 7.2.7.

Utilisation of wearable computers for other emergency services is also being developed. Haniff and Baber [114] describe interface- and technological requirements and experimental designs of wearable computer systems for Fire fighters and for the Police Force.

7.2.7 Assistance to the handicapped

7.2.7.1 Eye impairments

Thad Starner, an MIT researcher, has built a computer system for his grandmother, who began loosing her eyesight some years ago. The system magnifies and intensifies images, allowing her to read again. The work is based on a more sophisticated wearable computer system created by Starner and Steve Mann, called a "visual filter", used to map around blind spots. The technique is used to move images from the centre of one's visual field to the periphery, or vice versa, depending on the eye impairment that needs to be omitted [12]. MIT professor John Wyatt has started experimenting with retinal implants [115, 116], making it possible to regain vision even for some entirely blind persons.

Steve Mann has also constructed and is an active user of a tactile feedback vest (briefly described in [98]), allowing blind persons to physically feel obstacles ahead or to feel their distance to the walls of the hallway they're walking down. Commercial products acting similarly, primarily aimed at enhancing gamers' experiences (not using wearables), are also available [117].

7.2.7.2 Hearing impaired

MIT Researchers Thad Starner, Josh Weaver and Alex Pentland have built a wearable system capable of translating the hand signals of American Sign Language into spoken English [12]. Using speech-to-text products like the software outlined in chapter 4.3.1.1.1 it would also be able to outfit deaf persons with a wearable that would transcribe what is being said to them, dramatically improving quality of life by making it possible for them to function better in social and work-situations.

7.2.7.3 Speech impediment

For persons with a speech impediment, using a wearable computer with a discreet display to prompt the manuscript of a speech may help them to talk more coherently. [12].

7.3 Some known cases

Wearable computers have already been embraced by a handful of organisations, using them in innovative ways to improve efficiency and quality in their processes.

7.3.1 Case: BOC Gases

BOC Gases (NJ, USA) sells Nitrogen, Oxygen and Carbon dioxide to manufacturing customers. BOC has implemented a "wearable control-room", allowing plant maintenance workers to respond more quickly to situations which need their attention. This has, according to Xybernaut and Mark Grace, Global Director of Food Technology at BOC Gases lead to that "The plants using this system are achieving single- and double-digit increases in productivity". Also, due to shorter response time, quality of the products has been improved [118].

7.3.2 Case: Framatome

Framatome Technologies, Inc., based in Virginia, USA, performs steam generator inspection in nuclear power plants. They have started using wearable computers to track inspection and maintenance equipment inventory more efficiently and accurately. According to Xybernaut, "The MA IV™ reduces onsite packing and unpacking time by 50% while improving capture of critical inventory and safety information, thus dramatically improving the control of multimillion dollar assets." [119]

7.3.3 Case: Boeing

Boeing has been equipping factory workers with wearable computers since June 1997 to speed up production. Using Augmented Reality (see also chapter 7.1.3), the workers can see assembly diagrams, digitally added to their workspace, reducing the need to work with cumbersome paper diagrams. [120, 121, 122] According to the CNN article, Boeing's experiences are that using the wearable computer system, the wiring can be done up to 50 percent faster than with current methods.

7.3.4 Case: Remote Maintenance Assistant

General Dynamics [123] has built a system they call "Remote Maintenance Assistant" that enables maintenance and training personnel at remote or multiple sites to:

- Access technical, logistics and training information about supported systems
- More accurately and rapidly perform maintenance operations on complex systems
- Collaborate and share computer applications, data and information between distant locations
- Support a "paperless" work environment in both field and garrison

General Dynamics currently has several RMA projects in place. One, in cooperation with the program manager, Abrams Tank System, is operating at the M1A2 Abrams Fielding Site at Fort Hood, Texas, and is linked to two separate General Dynamics facilities. Another project, with the CECOM Logistics Readiness Center, is demonstrating the use of the RMA as a "tele-maintenance" pilot project. RMA is based on the commercially available VIA II Wearable Computer running Windows 98 [124].

7.3.5 Case: U.S. Customs

Using a system from Sentel [125] and Xybernaut, U.S. Customs officers on the Arizona-Mexican border can work more efficiently; querying databases to check whether vehicles are stolen while remaining in the proximity of the vehicle and its driver. Previously, such querying was done manually: writing down the registration-information on paper, then looking it up on a terminal located away from the road, or by relaying the information over radio to a second officer. The new system allows the officers to read aloud the licence-plate information; the wearable computers use speech-processing software to create the database query. The results of the query appear within 3-5 seconds on the officer's personal display. The introduction of wearable computers in this environment shortens the waiting time for drivers crossing the borders, and fewer officers are needed [126, 127]. Edward G. Newman of Xybernaut Corporation has stated that the number of database queries has improved from 15 to 75 per hour after introducing the wearable computers.

7.3.6 Case: U.S. Army

According to an article in Federal Computing Week [128], the U.S. military has already experimented with applications of a wearable computer to aid in servicing helicopters.

> "[Using equipment by Xybernaut adapted for wireless use] lets technicians refer to maintenance manuals as helicopter maintenance is in progress. By remotely accessing electronic manuals the head-mounted device saves technicians from having to climb down from the helicopter check the manual and reclimb the helicopter each time they are uncertain about how to tackle a problem."

U.S. Navy has also tried out Xybernaut units on the USS Princeton according to Scott Brzezinski, director of federal sales at Xybernaut. "Navy technicians are using six of the units connected to an on-ship wireless network which in turn uses satellite communication to access supply databases on land. The wireless connection lets sailors order parts without missing a beat."

According to Bass [12], NATO troops parachuting into Bosnia wore or were planning to wear ViA Inc.'s wearable computers equipped with software capable of translating English into Croatian, French, Russian and other languages potentially useful in a war zone.

7.3.7 Case: Law enforcement

According to a 1998 article in Federal Computer Week [129], a wearable computer system called "Team Leader" originally developed for the U.S. Department of Energy to collect information digitally in the field when inspecting peace-treaty sites, such as foreign weapons depots, is now being adapted for crime-scene investigators.

> "Law enforcement officials scattered among multiple crime sites could use the system to communicate wirelessly. From a central site, the director of a crime scene field team

could communicate with investigators clad with a head-mounted video camera, a digital still camera, a wrist-mounted keyboard, a laser for taking precise measurements, a satellite-based Global Positioning System and core hardware and software tucked away in a vest.

Investigators in the field could send information, such as video images, to the director via wireless modems, and the director could make suggestions on what to look for at the crime scene. The director also could transmit information, such as aerial imagery or crime reports, to the investigators in the field."

7.3.8 Case: Det Norske Veritas

The Norwegian foundation Det Norske Veritas (DNV) [130] has recently experimented with wearable computers [131]. A ship inspector has carried an IBM wearable prototype with him on duty, having installed thousands of pages of manual documents, allowing him to easily access reference information regarding the procedures of certifying the ships he visits. DNV has not yet implemented wireless access to the headquarter mainframes, but is planning to do so. The previous way of inspecting the ships included a lot of duplication of work. The inspectors would make notes in the field, and subsequently filling in documents on a notebook computer – too large to carry around the boat. According to project manager Thomas Mestl at DNV, the deployment of wearables to the workers in the field is a natural continuation of the notebooks they use today [132].

8 Changing the rules of the game: social impact of wearable computers

Steve Mann writes in [98]:

> "I realise that some people see me and my invention as a potential threat—like the Borg of *Star Trek* fame: "You will be assimilated." Clearly, there are important philosophical issues to be explored. Not only is there the danger of the technology being used to monitor people to make them into obedient productive cyborgs, but there is also the potential that people will become too dependent on this technology. My goal as a responsible inventor and engineer, however, has always been to encourage the development and manufacture of wearable computers as a means of personal, not institutional, empowerment. That will make worthwhile all the obstacles and challenges I have faced during my more than 20 years of developing this technology."

The introduction of wearable computers in any corporate (or personal) environment will undoubtedly have an impact on formal and informal organisational structures.

According to Mr. Newman of Xybernaut Corporations, there has been the experience in organisations where wearables have been tested that Labour Unions have initially reacted to the wearables. After realising that the wearable eases the work rather than interrupt or interfere, however, the workers have accepted and embraced the wearable technology.

Steven K. Feiner at Columbia University has written a paper on the social consequences of wearable augmented reality systems [133]. He outlines different issues related to the acceptance of wearables in society:

8.1.1 Tracking accuracy

There are several technologies, as mentioned previously in this thesis, which can be used for tracking a wearable device for the purpose of for example providing location-specific information or behaviour. Very precise location-information for each individual using a wearable computer can be expected to exist, and issues arising from this may be: during conversation/collaboration/communication with other users; how precise information does the user wish to give? Sharing of tracking information can be valuable for the conversation, and may become the "polite thing to do", according to Feiner [133]. For example, even though the users are collocated or otherwise can see each other directly, sharing tracking information could provide a more stable interaction by improving the accuracy of gestural references and adding information about temporarily occluded features. For example a user may release information about his hand, so that the others can see where he is pointing, whether or not his hand is obscured. Outside direct conversations, a user still may be comfortable releasing precise tracking information to a small, select group of friends and colleagues, while for others it will be enough to share the location with less accuracy (e.g. what building or even just what city the user is in). In some cases, the user might even want to intentionally deceive other users regarding his location, or to deny tracking at all.

8.1.2 Appearance and comfort

Determining the time during a conversation, without making an embarrassing and impolite look at the watch, is just one of many small, yet useful features that become available with a head-mounted display. Other uses include the possibility to scroll through notes while giving a talk or in a meeting. One of the things that are holding back many of these uses, is the looks and feels of current wearable display technology. The term "Head Mounted Display" implies that what is being used needs to be mounted onto the users head, rather than just worn like an ordinary set of eyeglasses or contact lenses. There has been made several progresses in the field of display technology (see a separate overview previously in chapter 4.3.2), but still a user of a wearable computer with few exceptions will be stigmatised as if he or she came right out of some science-fiction movie, and this is of significant importance to change before wearables will become a mainstream technology.

8.1.3 Mobility and collaboration

> "When users are mobile, they no longer spend their computational time in front of a solitary desk. However, mainstream mobile computing currently supports only those collaborative activities within which it is appropriate to devote one's attention temporarily to a laptop or hand-held device. In contrast, mobile augmented reality can make it possible for computation to be integrated with essentially any activity. Thus, new collaborative applications could support face-to-face conversation without the need to divert one's attention to a PDA, let alone pause to flip it open."
>
> "Mobile wearable augmented reality systems will make it possible for active users to move into and out of the presence of others, as regularly and smoothly as we currently do when we are not computing. […] User interfaces will need to change to take advantage of these capabilities. For example, inviting a new participant to join us

> might be accomplished with the same voice, face, hand and body language that we already user to initiate an unaugmented conversation." (Feiner, [133])

8.1.4 Implications for personal privacy

There are several privacy issues being raised by individual wearable tracking devices and wearable computers with audio and/or video recording capabilities. Steve Mann has described a "safety net" of wearable computer users who watch out for each other [134], monitoring information that their fellow "safety net" group members transmit in case of for example increased heart rate or similar stress-symptoms. Feiner outlines a possible scenario [133]: in a world in which networked personal wearable computers with recording devices are commonplace, the consequences may be surprising:

> "Suppose that some organisation were willing to pay individuals a small, but adequate, sum to acquire real-time access to their recorded experiences. To make such an arrangement more attractive, access might be controlled as the individual saw fit; for example, automatically expurgating material captured at work and home, or interaction with the user's friends and colleagues, effectively addressing that user's concerns about maintaining some amount of privacy. An individual user's material may be of little or no value by itself, but consider what might be done with the aggregate time-stamped and position-stamped recordings of a very large number of users.
>
> Massively parallel image and audio processing could make it possible to reconstruct a selected person's activities from material recorded by others who have merely seen or heard that person in passing. Imagine a private two-person conversation, recorded by neither participant. That conversation might be reassembled in its entirety from information obtained by passersby, who each overheard small snippets and who willingly provided inexpensive access to their recordings. The price paid for such material, and the particular users to whom that price is offered, might even change dynamically, based on a user's proximity to events or people of interest to the buyer at that time. This could make it possible to enlist temporarily a well-situated user who may normally refuse access at the regular price, or to engage a user's wearable computer in a "bidding war" among competing organisations, performed without any need for the user's attention.
>
> While unauthorised commercial use of the actual material reconstructed this way (e.g., appropriation of a user's audio or video likeness) could face legal restrictions, merely acting on information derived from this material may not be illegal. Nevertheless, the possibility of having one's actions traced through the sum of many small and unavoidable interactions is an unsettling prospect."

The outlined technology could for example be used to monitor the activities of a competitor at a large conference. Contracting a third party to harvest electronic material from nearby attendees and analyse it may make it possible to piece together significant portions of the competitor's interactions at a lower cost than "tailing" the competitor oneself, or hiring someone to "tail".

> "Ensuring the confidentiality of even the most mundane interactions might become extraordinarily difficult." (Feiner, [133])

The same technology, given enough cheap processing power and storage space, could also be used for the benefit of the single users: sharing their recordings continuously through open, co-operating set of servers could answer queries like "Is bus number 9 late?" or "Has anyone seen Martin today?". There are, however, usually more cost-effective solutions than complex video-analysis to answering such queries. For example the first of the above questions could be answered by a continuously updated, dynamic web-page from the bus-company, based on real-time GPS-data from the buses. The second query could be answered by a ubiquitous computer system (see chapter 9) in the building where you'd expect to find Martin (or Martin could be releasing his own tracking-information to you, if he considered you to be a friend of his, see chapter 8.1.1). Both systems would probably be cheaper to implement than a gigantic image-analysis project. However, as CPU-power and storage prices drop and capacity increases (Moore's Law, [5]) such a system may become available in a distant future.

Less sophisticated equipment, available today, could still have implications for personal privacy when used for malicious purposes, as described in the following article, talking about MIT researcher Thad Starner:

> "By adding a small camera to his outfit, Starner can also run a face-recognition program. The uncertainty that comes from seeing a face you recognise but can't quite place is transformed into an image that comes complete with name tag and annotated notes on your last conversation. "While sitting here talking to you, I could gather online information telling me when you got married, how much you paid for your house, your credit card history, and your medical record," says Starner, who frowns on this kind of "social hacking." But because he knows how to do it, he is hypersensitive about designing tamper-proof systems. "I can be a real crypto nut," he says. "The whole purpose of a wearable computer is that you control it, not the environment. I want to make technology that inherently protects the user. You have the right to your own bits." " [12]

Protecting personal information in a world of computers integrated everywhere may be possible, but at a price. In the words of Neil Gershenfeld, co-director of the Things That Think consortium at MIT Media Lab:

> "There's this paranoid notion of eavesdropping, that the very walls in the room could be aware what you're doing. But it's very important to understand that those are social, not technological, questions. Right now you really are digitally unprotected -- people have access to all the information that comes and goes, and you have no means to manage it. But there is a very good cryptographic protocol to control your information.
>
> I see privacy as becoming the social trade-off. For example, if I'm wearing a computer in my shoe and walk into my store and have my identity turned "on," someone could come breezing up and say, "Welcome, Mr. Gershenfeld, we know you need a shirt -- it's over here, and here's your size, and we'll give you a discount because you've given us such good demographic information and you spend a lot of money." And I'll go home and get junk mail. Or, I can leave my identity "off" and can do a zero-knowledge cryptographic protocol that lets me buy the shirt without the store learning a single piece of information about me at all. But it costs me more and I get worse service.
>
> It's not up to me as a technologist to decide what that trade-off should be. But, crucially, it's up to me to give people a knob to control that, a means to control the information that comes and goes. And that is certainly missing right now." [4]

8.1.5 Implications on social interaction

Studies by Swedish researchers Weilenmann and Holmquist [135], using a simple wearable device called a "Hummingbird", shows that the ability to track other users within a geographical range (vaguely similar to the current utilisation of "BuddyLists"/ICQ [136] on the Internet today) was quickly adapted by a user group not normally exposed to wearable technology. One interesting finding was that users had more use of the Hummingbirds in activities they did not consider the devices to be meant for. The devices quickly became used in social settings (looking for colleagues to have lunch with and similar), rather than the organisation of their professional activity, which they considered the prime objective of the trial.

9 Ubiquitous Computing

While wearable computers are attached to their user and is basically reacting to the user and his surrounding environment, ubiquitous computing is a different approach. The phrase, coined by Mark Weiser in 1988, describes a vision where computers are embedded in walls, tabletops and everyday objects. In ubiquitous computing, the "user" can interact with several computers at once, each invisibly embedded in the environment and wirelessly communicating with each other. The concept is closely related to the idea of "smart rooms" [137], where a room might contain multiple sensors that keep track of the people in the room, their locations and actions. Ubiquitous computing can perform anything from environmental control (turning on/off air conditioners as people enter/leave the building), "proximate selection" (sending a print-job to the physically closest printer) or automatic logging of who goes where (diary) to presenting relevant information to a user as he/she enters the room ("Magic Wall" [138]).

In an article by Rhodes et al, the differences between wearable and ubiquitous computing are outlined [139]. One of the first issues that arise is privacy: a ubiquitous computer system has the ability to be monitoring all the users/visitors of a location at any given time, storing information about each individual's actions, preferences and locations, with the subsequent potential to reveal the same information to others, now or in the future. The most useful information also appears to be the most personal. Logging individual's locations may give positive outcomes like the ability to display relevant information on "magic walls" [138] throughout that user's day, but, according to Rhodes et al's article, this information, if centrally stored, may also become a target for subpoena in juridical processes. Situations may also arise where users do not wish to be monitored, having reasonable fear that the information registered may not be kept secure, or used solely to their advantage: registering buying habits and customer profiles by providers/shops to increase sales is one example. Another example presented in the article is a businessman entering a competitors company to negotiate a contract, he would probably not wish for all his personal profile information to be uploaded to their system, where it might be viewed to gain an unfair advantage.

Wearable computers largely solve the above problems; the user carries with him the sensors and camera(s) instead of being monitored by the room:

> "In the purest form, the wearable user would do all detection and sensing on her body, requiring no environmental infrastructure at all. […] Because the wearable always

> travels with the wearer, personal profiles never need to be transferred to a new environment. And because a wearable might stay with a user for many years her profile can automatically evolve over time. Furthermore, wearable computers are an inherently more private location for sensitive data because it never needs to leave the person. If the data is never transmitted it becomes much harder to intercept, and the distribution of personal profiles across several wearables (possibly owned by many entities, each with a vested interest in keeping his own data private) makes them a less convenient target for compromise, subpoena, or strong-arm tactics." (Rhodes et al, [139])

Potential problems with wearables compared to ubiquitous computing relate to localised information: if information about a single location gets updated, every wearable needs to be given the new information. Also, if several wearable units try to control a resource (a stereo, a big-screen display or similar), it would be more appropriate if the resource (device) itself had some built-in "intelligence" to handle the requests. It would also be beneficial if the resources identified themselves and their services through a unified interface, so that each wearable didn't need to know all possible different devices it might encounter. Such interfacing might become available with Jini [140, 141], a new connection technology in the works by Sun. Another approach is the Hive agents platform described by Rhodes et al [139].

Table: Features provided by Ubiquitous computing versus Wearables (source: Rhodes et al [139])

Feature	Ubiquitous	Wearables
Privacy		X
Personalisation		X
Localised information	X	
Localised control	X	
Resource Management	X	

In J. Pascoe's article about contextual capabilities on wearable computers [88], he states that contextual resource discovery bridges the gap between wearable and ubiquitous computing. The wearable computer provides the core set of services familiar to the user, while ubiquitous devices complement or augment the wearable system, offering new or improved services.

10 Recommendations for companies wishing to deploy wearable technology

10.1 Wearables in industrial sector

Boronowsky et al [142] has presented a project of which the main focus is the application of wearable computing technologies to support the maintenance (especially the inspection) of a large amount of industrial cranes, distributed over the large area of Stahlwerke Bremen GmbH (a steel plant). They have concluded "To achieve the full benefit of wearable computers, its application should be accompanied by a change in the existing information technology of a company".

Regular industrial processes, such as inspection of technical devices, are often supported by information technologies. Due to limitations in conventional computer technology, it is not feasible with computer support during the complete process. Boronowsky et al [142] divides the tasks into computer-aided tasks and manual tasks and defines them:

Computer-aided task: Conventional computing technologies can be applied during this task. In this task the usage of a computer is the primary job which will take the main attention of the user.

Manual task: The execution of this task is not computer aided because the application of a computer is not possible or practical.

A process is usually a mixture of the two types of tasks. Planning of activities can be a computer-aided task, and this can instantiate a manual task (e.g. an inspection) through a work order. During a computer-aided task, changes can be handled flexibly (e.g. if a member of maintenance staff falls ill, the work order can be re-routed to a co-worker). If, however, the worker brought with him the wrong type of documentation, or if unexpected problems come up during inspection, the manual task can be considerably delayed.

Wearable computing is one way to reduce the amount of manual tasks in an industrial process. Owing to the characteristics of a wearable computer, a number of manual tasks can be executed as wearable-aided tasks, as defined by Boronowsky et al [142]:

Wearable-aided task: Wearable computing technology can be applied during this task. The usage of the wearable computer is not necessarily the primary task.

> "In a number of cases wearable computing is a chain link between two computer-aided tasks, which were formerly (i.e. without a wearable computer) intermitted by a manual task. By using wearable computers in an industrial process it is possible to apply information technologies over a wide range. […]
>
> There are a number of ways how a manual task can be substituted by a wearable aided task (In practice the wearable-task will not completely substitute a manual task. There will still be a smaller manual task left after substitution). The most important substitution modes are:"

Pure substitution, adapted substitution and reorganisation, as defined by Boronowsky et al:

Pure substitution: The wearable computer is used without changing other tasks of the process. The application of the wearable computer has mainly local effects. The replacement of a printed maintenance manual by an interactive digital one is an example of a pure substitution. Another pure substitution is the replacement of data acquisition by pen and paper with a voice controlled data acquisition tool.

Adapted substitution: For a better integration of the wearable aided task into the whole process, the computer aided tasks before and after the wearable tasks are also modified. For example, a computer aided planning task is adapted in order to transfer the actual planning to the wearable computer. Or the computer-aided task that evaluates the results of an inspection automatically receives the inspection results from the wearable computer.

Reorganisation: In order to achieve the greatest profit of wearable computing technologies, the whole process has to be reorganised. In a process with manual tasks, the computer-aided tasks are generally designed to support the manual tasks. One possible kind of reorganisation can be called *individualisation*. The inspection of a number of technical devices, for example, can be organised as a separate planning task for each device. In this case each device is handled individually. Every instance, for example, gets its own inspection cycle and problems that were detected during inspection are brought into context with this device. This approach is an information-intensive process, because a lot of individual information has to be processed. In most cases individualisation goes along with an organisational overhead. Especially if manual tasks are executed, individualisation is hard to realise. Therefore, in real industrial applications, individual devices will be handled in a more global way. Wearable computing technology can be used to achieve a greater individualisation, because the necessary information will be processed with the wearable computer.

Reorganisation/Adapted substitution can also for example consist of programming a dynamical software system that can provide the necessary information and means to record the necessary data, for example the "Remembrance Agent" by Rhodes [8] or contextual awareness [88].

Even introduction of a "pure substitution" can have significant impact in industrial applications, for example radically decreasing the time of feedback for inspection data: if collection is done with pen and pencil and later entered into the computer manually, there is a significant delay, and also potential for errors.

10.2 Wearables in business

As several of the cited authors have emphasised, wearable computers can be an excellent tool for personal empowerment. The customisation of both the physical and the software user interface is highly personal, as the user and his wearable adapt to each other over time. If a company equips its employees with wearable computer units, possibly with a "shared memory"-feature as described by Mann [7] (see also chapter 11), consideration should be put on the subjects of privacy; e.g. who will be or should be allowed to see what I told my clients? Will the users' interactions, internally or externally of the company, change because informal conversations may also be recorded? I believe few employees will enjoy all the features of a wearable if they don't feel secure that it is present to work *for* them, not against them. Deployment of wearable computers in an organisation may have significant impact, as long as the content generated (if any) is treated with caution and respect towards the employees.

11 Documentation of experimental implementation of a wearable computer system for real-time capture of audio/video

Part of the thesis assignment consisted of building and documenting a working prototype of a wearable computer application, specifically: a video capture-system with server backend analysing capabilities, enabling searching of captured video. The idea was that a wearable computer user would be able to easily access a visual memory of his/her actions and meetings in the past – possibly eliminating the need for taking notes at meetings et cetera. It would also open up for the possibility of a "shared memory" as outlined by Mann in [7] – that users could access other's "memories" and thereby have a recall of information that one need not have experienced personally.

We hoped to analyse the continuous sound and video-stream, performing facial recognition, text and speech annotation/transcription.

This work was to be performed at Andersen Consulting Technology Park, Sophia Antipolis, France, during 2 sessions of 2 weeks during the autumn of 1999. Unfortunately the work was not finalised due to several factors, mainly delays in supply of necessary software components. I will, however, outline the model we tried to implement, and describe necessary steps to complete the project.

We had available a wearable computer unit, a Xybernaut Mobile Assistant IV [26], running Microsoft Windows 98, equipped with a

- Nogatech [143] USB video-capture-adapter
- Xybernaut head-mounted camera
- Simple AVI recording software

Additional specifications/wishes, included "intelligent" recording software to save power, e.g. not transmitting a still image, or (more advanced) not transmitting unless there is a face or text in the picture, or automatically and intelligently segmenting the video into pieces for easier transfer and parsing. Steve Mann had done some previous work in this field [40].

There was significant uncertainty whether the quality of the video captured would be high enough to get intelligible analysis results. If not, we had a few other alternative options:

- If we were unable to get good enough video on current configuration we would try to capture higher quality video at a lower frame-rate, or high quality still images once or twice every second.
- Low-tech alternative: if none of the above worked: capture video and transmit using same technology used in "surveillance"-toys, e.g. analogue video transfer through antenna and into video-capture-board in a server. Then use wireless network and wearable to retrieve search results.

11.1 Hardware

11.1.1 Network components

We ordered, but did unfortunately not receive in time, wireless LAN equipment from Proxim [144], capable of working at speeds up to 10-11 Mbps. We had available equipment that could transfer approximately 2 Mbps between two computers, but this was estimated to be too low for high quality continuous video.

11.1.2 Storage/server-solutions

At the Andersen Consulting facilities in Sophia Antipolis, we have access to several hundred gigabytes if necessary.

11.2 Software

11.2.1 Video analysis

We were looking for software to perform as many as possible of the following tasks:

- Automated system to analyse and store annotated/transcribed video from wearable
- Preferably possibility of face- or voice-analysis to recognise the persons in the video/audio-stream
- Preferably automated, working continuously
- Preferably storage in database
- Retrieval mechanism (web-based), possibly with several different forms of output (audio + transcript + video OR key frames/"storyboard" or similar)

Through the web, we found the following options:

11.2.1.1 Commercial

- Virage VideoLogger and AudioLogger [145, 146] is a video analysis system for professional media companies capable of transcribing audio (and recognising who is talking), reading text in the video signal and intelligently segmenting the video-stream, making it searchable for later retrieval e.g. through the web.
- MediaSite [147, 148] (formerly known as ISLIP Media, Inc.). MediaSite Publisher with "Speech Indexing Module" is a piece of software that performs similar tasks as the Virage products.

11.2.1.2 Under research

- IBM CueVideo [149, 150] is a media-indexing system similar to the above mentioned commercial technologies. Combined with IBM's ViaVoice-technology, it can, like the others, transcribe voice.
- Andersen Consulting Emerging Technologies Network [151] is a digital asset management system, but appeared not to be exactly what we were looking for in terms of automatic segmentation, audio transcription et cetera.

None of the options mentioned above were unfortunately obtained in time for trials with the wearable computer, and software for video-analysis therefore became the main "missing link" of our project. We did, however, establish contact with several of the vendors/suppliers and received positive responses from, among others, IBM's research labs.

In addition, we experimented briefly with real-time facial recognition using software called FaceIt [152].

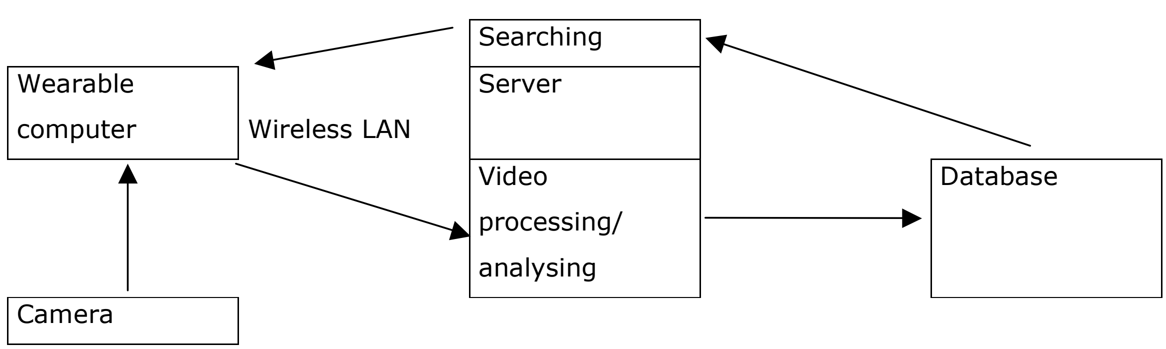

Figure: schematic description of desired system implementation

12 Future of wearable computers

There are various trends that become evident in the near and more distant future of the technology I've discussed in this thesis. In a previously cited interview about "Things That Think", published in the Salon Magazine, Neil Gershenfeld of the MIT Media Lab concluded:

> "[Janelle Brown, interviewer:]
> When you look at something like the computer shoe, though, it requires that the computer be in the shoe, that the shoe be communicating with lots of objects around you, that there will be other people wearing the same shoes, and that the shoes be affordable to me.
>
> [Neil Gershenfeld:]
> If I talk with presumptuous certainty about this future, it's because everything I talk about in the book works in the MIT Media Lab. These are things that really are in product development pipelines.
>
> It's not going to get rolled out like the Euro. Initially the stuff is going to come out in a couple places. One place is where there's a desperate reason to solve it -- sensory car seats that help save babies' lives (a product the MIT Media Lab recently manufactured to protect infants from airbags), or using wearable computing to read airplane repair manuals so that mechanics don't have to keep going back to the library. Those are the niche markets where you don't ask that question, it just has to happen.
>
> The second vector will be the new generation who's unwilling to live without these capabilities. The third vector is enabling the capabilities themselves, making them possible. What's going to be playing out over the next decade is a creeping and coming together -- an interesting confluence of those three things.
>
> We're made out of atoms, and we will be for the foreseeable future. What's interesting is how the digital world relates to the physical one we live in. The story for the next 10 years will be about breaking down the barrier between the bits and atoms. Eventually, it's going to become a very familiar notion, even though right now it seems elusive and quirky." [4]

There is a tendency towards integration of existing technologies: in a not too distant future, there will be no need for carrying several devices (cellular phone, PC, pager et cetera). We can expect to se more "communicator"-type units like the prototypes presented by cellular phone providers Ericsson [153] and Nokia [154], providing computer/PDA-features as well as telephone and possibly videoconferencing.

Image: Ericsson concept design of a "Communicator"-unit (Source: [153])

Image: Nokia concept design of a "Communicator"-unit (Source: [155])

Wearable computers will most likely evolve to "Smart clothes" [156, 157] and their designs will be much less intrusive than they are today. Designs will be fashionable [158, 159, 160] and as an example, MIT and the designer company IDEO have co-operated and presented two different design suggestions for wearable computers we might see in the future [161].

We can also expect to se improved user-interfaces, as researchers are developing so-called "affective computing" to make the computers "more human" in their interaction with the users [12, 162, 163, 164].

Regarding Ubiquitous computing, we can expect to see that more and more "intelligence" will be built into office- and domestic appliances. A perhaps far-fetched domestic example is found in the article "There's a PC in my salt shaker" [165], where researcher Hiroshi Ishii from the Tangible Media Group at MIT Media Lab presents bottles of soy sauce announcing the weather report when they're opened. "I never wanted my mom to boot up a PC, or learn how to use Internet Explorer. It's irrelevant to her life," he states, exemplifying how ubiquitous computing may change our lives in the future. A more realistic product are the new refrigerators built by Electrolux, with internet access on a touch-screen display and a bar-code scanner mounted on the door [166]: "The device invites appliance owners to scan near-empty jars and milk cartons that are running low, and add them to a digital shopping list. The list would then be beamed over the Internet to a grocer selected by the consumer."

In a distant future, we might encounter "true cyborgs". Cyborgs in the sense that they have substituted or augmented body-parts with technological implants. As mentioned in chapter 7.2.7.1, researchers are experimenting with retinal implants, and these technologies could be applied for persons that are not blind in the first place as well, creating "super humans" with enhanced vision. Other researchers have experimented with "thought control" [167], and primitive technologies needed to "jack in to the brain" has been demonstrated [168]. Researcher Kevin Warwick at the University of Reading, UK, is experimenting with implanting computer chips into his own body and has great ambitions on what will be possible to achieve, including two-way communication between the brain and a computer [169, 170, 171].

13 Conclusion

In the next five years, I believe that the most realistic will be that we will have cheaper, smaller and more powerful wearable computer units than those commercially available today. Non-intrusive displays integrated in ordinary glasses or sunglasses and Palmpilot-sized main units with batteries lasting for an entire day or more of operation are not unrealistic to expect. The wearables will be powerful enough to perform for example real-time translations [172], video-conferencing and other forms of supporting real-time collaboration. They will also have an improved context-awareness compared to what we see today: using cheap GPS-sensors (it is possible to get a cheap GPS-sensor at the size of a postage stamp already today [173]) and/or other positioning systems as described earlier in this thesis, we can expect them to "behave more intelligently" appropriate to the situation.

The fact that these units soon will be more powerful (both regarding CPU-power and battery capacity), more comfortable to wear and have more pleasant looks will have an impact on early-adopting organisations and individuals. I believe we will see more and more people utilising wearable computers outside the specialist niche markets within the next few years. It will, however, take several more years before wearable computers become as widespread as for example cellular phones are today.

Wearable computers can and will significantly change the way many professionals work, and possibly the way many individuals live, as described in chapter 7. Over the next few years I believe we will see deployment of wearable computer units on a broader scale in the niche markets, like ambulance personnel and industrial maintenance. On the other hand, for example knowledge workers will be slower to pick up the new technology until the relationship of benefits versus “costs” (for example regarding appearance) improves.

As we see wearable computers becoming more commonplace, it is important to keep in mind privacy-issues that may arise, as discussed previously in chapter 8.1.4. This is an important aspect to keep in mind for both the users and the developers of the technology.

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