Issues in Wearable Computing: A CHI 97 Workshop

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"Wearable computers represent a new paradigm in computing." This statement is a good sound bite and undeniably true but what does it mean? Finding meaning in this statement was the purpose of a two day workshop on wearable computers organized by the four authors of this paper, at CHI 97 in March, 1997. The workshop was attended by 37 people representing 21 different organizations. The attendees are listed in the Appendix. This white paper is a report on that workshop.

The issues associated with wearable computers can be broken into five categories: terminology, market, technology, people, and application. This report will be divided into these five categories.

Wearable Computer Terminology

What is a wearable computer? Is a calculator worn in a shirt pocket a wearable computer? Is a laptop computer wearable? How about a PDA? A wristwatch computes time, and we wear it; is it a wearable computer? Is a pager? How about a two-way pager? Is a cellular telephone a wearable computer? After all, it contains a microprocessor. What about a hearing aid, personal sound system, or pacemaker that contains a microprocessor? What distinguishes a "wearable computer" from a personal electronic device that contains an embedded computer? These are the types of questions that the workshop discussed while debating the terminology question.

The terminology used to describe wearable computers and differentiate it from other types of computers and computing focuses on three aspects: how it is physically used, what is the environment of use, and what is the application?

Usage of the Wearable Computer

Two desirable characteristics of a wearable computer are use while in motion and use with one or both hands free. Neither of these characteristics characterize fully the wearable computers, but both convey the general spirit of what many desire in a wearable computer.

Mobility is a characteristic of several different types of computers; in particular "wearable computers" are as mobile as the individuals wearing them. Laptops are mobile. Nomadic computers, as pioneered by Steve Roberts, founder of Nomadic Research Labs (larger computers attached to bicycles or other transporting mechanisms) are mobile. So although everyone agrees that wearable computers are mobile, not all mobile computers are wearable, unless we extend the notion of "wearable" to include vehicles and the like.

"One or both hands free" is also a desirable characteristic. Wearable computers that leave both hands free include systems with speech-based input and other evolving hands-free input devices. Many current wearable computers use some form of single hand based input device such as a chording keyboard, a dial, or a pointing device.

Environment of Use

Wearable computers are used in a variety of different environments. Some are used without any environmental support. They are stand alone devices for data collection or delivery and are connected to an environment only for discharging their data or collecting new data for delivery in a process separate from their normal usage.

Wearable computers are also used to connect to an environment generally but not universally available. They can connect to the Internet, telephony infrastructure, GPS for location awareness, or a local area network, for example.

Finally, wearable computers may connect to a specialized environment (for example, Boeing's "work cell") such as a room wired with special-purpose position monitoring sensors or special purpose cameras.

Wearable computers overlap with but are different from ubiquitous computers. Ubiquitous computers may or may not be worn. Active badges, for example, are worn. Smart desks, for another example, are not worn.

Application of the Computer

Some people advocate using the applications for which a computer is used as the defining characteristic. Wearable computers provide for private, information based applications. Thus, terms such as Personal Information Processing System and Personal Information Architecture were proposed as alternatives for the term wearable computers.

Terminology Conclusions

Part of the reason for this flexibility in definition is that there is considerable diversity in possible avenues of pursuit in this very broad field of research. That is, a wristwatch, with sufficient computational capability (e.g. heart rate monitor, wireless link to shoes, etc.) might fall under the general umbrella of "wearable computers" as well. Another example of such a system includes the portable maintenance aid designed to provide information to a technician at a maintenance site while some repair operation is underway. These "wearable information tools" generally provide the user with some sort of assistance.

Although we do not propose a set of definitions here and any definition will depend on agreement that does not yet exist on whether specific examples are wearable computer, we have explored some of the issues associated with such a definition and we have characterized wearable computer with respect to other terms. We have declared that wearable computers are nomadic and mobile but not vice versa. We have declared that there is an overlap between wearable computers and ubiquitous computers but no subsumption in either direction. We have discussed the extent to which both the "wear" and the "computer" are important. This certainly provides a context for the four discussions that follow: market, technology, people, and application.

Market

One aspect that colored many of the disagreements in both approach and philosophy among the participants in the workshop is the assumed market for their particular type of wearable computer. In this section we discuss the different types of markets and the assumptions made by various systems builders. We also discuss the problem of acceptance of wearable computers. What are the inhibitors to general acceptance of wearable computers and how can these inhibitors be broken down? We begin by discussing the market issues.

Type of Wearer

A fundamental source of much of the discussion during the workshop was the question of who was the target audience for the type of system under discussion. We identified at least four types of possible targets, each with their different characteristics.

- Expert User (Analogous to Programmer/Hardware Hacker)

This system is owned, operated, and controlled by the wearer of the system. The wearer is assumed to be a computer sophisticate not only capable but desirous of configuring their own hardware and software. A typical system is constructed from components and the main goal of the wearer is either exploration of the technology or the ability to access customized, special purpose applications. An expert user system is considered a personal artifact and is not shared with others. This system communicates and exchanges data with other systems at the level of communication protocols.

- Mass Horizontal Market User (Analogous to Home Computer User)

This system is owned, operated, and controlled by the wearer of the system. The wearer is not assumed to be a computer sophisticate capable or desirous of configuring their own hardware and software. This class of wearer demands ease of use and standard pre-programmed functionality. The wearer buys the unit off the shelf and the goal of the wearer is either perceived utility or enhanced social relationships. A system is considered a personal artifact and is generally not shared (or if shared, only with close personal friends or relatives). This system communicates and exchanges data with other systems at the level of data formats.

- Dedicated Vertical Application User (Analogous to Typical Office Worker)

This system is owned and controlled by the employer of the wearer. The wearer may or may not be a computer sophisticate and is often discouraged or prevented from configuring either the hardware or the software of the system. This class of wearer accesses standard pre-programmed functionality although depending on the environment, they may be willing to take training in the use of the system. The employer buys or creates a custom system that is pre-configured for the applications of interest. The system sometimes is required to operate in an environment which is unfriendly to electronic systems; i.e. wet, cold, or noisy. The goal of the wearer of the system is increased productivity. This system may be shared in the same fashion as other tools in the workplace are shared. This system communicates and exchanges data with other systems at the level of data formats.

- Physically Challenged User (Assistive Technology)

This system is tailored to the needs of a single individual with a unique set of disabilities. The wearer is not assumed to be a computer sophisticate capable or desirous of configuring their own hardware and software. This class of wearer also demands ease of use and standard pre-programmed functionality. The wearer buys a custom tailored system and the goal of the wearer is an enhanced ability to function in a predominantly non-disabled world. The system is desired to operate in many different environments and communicate with widely disparate external systems; i.e. automatic tellers machines, appliances, public transportation systems, etc. The system is typically not designed to be shared. This system communicates and exchanges data with other systems at the level of data formats.

Market Niches

As can be seen from the proceeding discussion about the types of wearers, we are recreating a standard dichotomy between vertical (specialized) and horizontal (general purpose) markets. General purpose systems are designed to attract a very large market and are suitable for many different applications. Consequently, they are optimized for no particular application but because of competition and economies of scale, may eventually become available more cheaply and readily than specialized single task systems. Specialized features are typically designed for a particular type of wearer and, consequently, can be optimized for their use.

It is worth noting that, historically, there is a divide between general purpose and special purpose features that narrows over time but that products that end up in the divide struggle for acceptance for some time prior to general adoption (or rejection). The time period mentioned at the workshop was seven years. That is, there is a seven year period from the introduction of a technology that is aimed at extending the range of general purpose devices toward special purpose applications to the acceptance of this technology.

Inhibitors to General Acceptance of Wearable Computers

We identified four inhibitors to general use of wearable computers in vertical markets and one additional inhibitor in the horizontal market.

- Ease of use of the user interface. The user interface must be natural for the wearers. Since these devices in the vertical market are intended to be productivity enhancers, user interfaces that lead to incorrect operation will decrease productivity rather than increase it. In the horizontal market, unless there is great utility perceived from the devices, complicated user interfaces will face consumer resistance. A challenge in the user interface area is to have the user interface be learnable in 10 minutes by a new wearer.
- Ergonomics and obtrusiveness of the device. The wearable computer itself must be light weight, comfortable to the wearer in all conditions of use, and operate for a long time without battery change or charge. Any head-mounted display (HMD) must not call attention to the wearer. In an industrial or military environment, the HMD can be clearly noticeable but the total weight of the unit must be low. In an industrial environment, the HMD should be no more obtrusive than a pair of safety goggles or hard hat. In the consumer environment, the HMD should be no more obtrusive than a pair of glasses. The ultimate test of obtrusiveness might be whether or not a wearer is able to gamble in a Las Vegas casino without challenge.
- Loss of dignity or self-determination. In an extreme example, if there were a potential for surveillance of the wearer, the system might be unacceptable (assuming we rule out systems designed for tracking prisoners, etc.). In other subtle ways, there was a general fear that systems might be used to manipulate people through control and observation.
- Necessity for new applications. Conventional desktop computing metaphors are inappropriate for wearable computers; i.e. display size, hands-free interface, speech-enabled applications, etc. This requires new user interface designs for applications destined to run on a wearable computer.
- Social acceptability. In the consumer market, a certain amount of obtrusiveness is acceptable if the wearer either achieves a great deal of utility from the use of the wearable computer or if it is socially acceptable to wear a computer. Social trends and fashion trends are difficult to predict but encouraging fashion leaders to wear computers will tend to break down barriers to general consumer acceptance of wearable computers.

Technology

The heart of a wearable computer is the technology used. It is the shrinkage of the components involved both in terms of weight and power requirements that makes wearing a computer a feasible activity. The actual computational portion of a wearable computer (the processor, memory, disks) received little attention at the workshop. The assumption is that they are either sufficiently small so as not to represent significant issues or that they shortly will be that small. This is perhaps also an artifact of the focus of the overall conference of which this workshop was a small part; i.e., Computer Human Interface. What did receive attention at the workshop were communication devices (treated broadly). Such communication devices included input and output devices as well as communication to elements of a system off the body and communication within elements of a wearable system.

Input Devices

Several innovative input devices that could be useful for wearable computers were either demonstrated or discussed at the workshop. Some of these devices were finger based.

A device that monitors finger joint movement was demonstrated. The device consists of finger mounted micro-accelerometers that transmit impact pulses across the skin to a wrist mounted receivers that transmit the pulse and finger identification to a palm top computer. Additional information can be input from the fingers by using angle detection in Data Gloves, thin film resistors in Cyber Gloves and myoelectric signals in the Cyber Finger. Use of the finger as a pointing device in a personal imaging system was also presented.

Other input devices discussed were based on using the mouth or face as an input device. One form of input was voiceless speech that converted lip motion to text via a lip-reading camera or myoelectric signals. Another was the use of facial muscles to trigger an input signal. Many of these devices are currently in the experimental stage.

Displays

Several different categories of displays were discussed at the workshop. These include head mounted displays, occasional hand held display with a keypad and a constant use hand held display.

Communication to Other Elements of a Computing System

Announced at the workshop was a no energy fiber communication system. A passive pico cell in a 15 ft. by 15 ft. room receives information over optical fiber and converts the information to a RF signal. The light to the RF converter is also driven by the light energy arriving over the optical fiber.

This system potentially has a very high bandwidth and its actual bandwidth is limited by the capacity of the receiving system. Thus, installation costs of this communication system would only need to be borne once and upgrade to higher speed communication systems would occur automatically as the wearable computers are equipped with higher speed receivers.

Communication among Elements of a Wearable Computer

Cables are one of the problematic areas of wearable computers. Cables are used to connect display devices with processors, for example. Every head mounted display currently in use requires a cable. Some input devices also require cables. The workshop discussed two approaches to eliminating cables from wearable systems. One of these is the use of the skin and the other is the use of clothing.

- Body based communication. The skin is capable of transmitting electric signals and can be used as a transmission medium. This is the basis of the finger input system demonstrated as well as demonstrations given elsewhere.
- Clothing based communication. Clothing can be made from optically based fibers and this can be used both as an internal communication infrastructure and a sensor for body stimuli. Body stimuli might include indicators of stress and mood as well as indicators of health.

People

The fundamental people issue is "what does it take to provide appropriate utility and ease of use to the targeted wearer community in the targeted environment". Within this capsule statement are four phrases that we now discuss in more detail: targeted environment, targeted wearer community, ease of use and appropriate utility.

Targeted Environment

Wearable computers represent a total reversal from the days when the computers had to be air conditioned and humidity controlled and humans did not. A wearable computer must accompany its wearer if it is to be useful in its assigned tasks. A typical computer wearer operates out of doors as well as in a more controlled environment. This means that the wearable computer must be usable in conditions of bright sunlight as well as conditions of darkness. It means that it must be usable in conditions of heat and cold, of dryness and wetness, and in conditions of dirtiness and dustiness.

It isn't necessarily feasible for a single system to be able to operate satisfactorily in all of these different environmental conditions but it is incumbent on the designer of a wearable system to consider the conditions under which it will operate satisfactorily and make those constraints known to the consumer of the system.

Targeted Wearer Community

We discussed four distinct wearer communities, each with its own needs. These communities are: the expert user, the mass horizontal market user, dedicated vertical application user, and the physically challenged user. Issues such as ease of use and utility will be different for each of these communities.

Ease of Use

Two, maybe conflicting, currents affect the ease of use of wearable computers. First is the user interface paradigm and second is the level of compatibility with existing desktop systems.

- User interface paradigm. The desktop metaphor with its files and folders is suitable for a computer system that is used mostly for writing, calculating and other activities that occur at a desktop. It isn't necessarily optimal for a computer system that is worn by the user and operated without a modern pointing device in a variety of environments. The user interface should reflect the types of applications for which the system is to be used and the fact that the system is worn on the body. This reflection may be as simple as using pockets instead of folders as an organizing icon but is likely much deeper. Additionally, the metaphor of the point and click graphical user interface (GUI) quickly breaks down in speech enabled applications or other cases lacking a pointing device.
- Compatibility with existing systems. Compatibility with existing systems both in the look and feel of a wearable system and in the ability to exchange data with existing applications is desirable.

Use of existing look and feel has the virtue of enabling wearers to utilize their existing computer skills and to transfer these skills back and forth to the desktop. This ease of learning and transfer assumes that wearers are already computer users which is not necessarily true. Depending on the wearer community the users may or may not want to move between their wearable system and a desktop computer. In any case, ease of learning is only one aspect of ease of use and compatibility with existing look and feel must be traded off with total functionality. On the other hand, compatibility with data formats of existing desk top applications is essential to enable data to be easily moved between the wearable system and other systems with which the wearer will be interacting (even if indirectly). It is unlikely that wearable systems are going to be processing data that is different in kind from the type of data already being processed by desk top systems and so ensuring compatibility of data formats is a matter of appropriately engineering the wearable systems. Translators and virtual software layers are existing techniques that can be utilized to gain data format compatibility.

Appropriate Utility

Wearable systems should be fit for the tasks for which they are used. This is a main responsibility of the designer of such systems. Fitness for use implies paying attention to safety and ergonomics issues. It also means providing the ability, if the task requires it, to collaborate with others outside of the wearers immediate environment.

- Safety and Ergonomics.

The safety issues associated with wearing a computer are two: (1). A wearer's attention is divided between the computer and other tasks being performed such as walking or driving. Clearly, paying attention to the computer at an inappropriate time could cause catastrophic results. Some forms of input and output are more attention dividing than others. Research is necessary to determine the amount of attention required to interact with a computer and to determine the amount that can be spared from everyday tasks such as walking and driving. (2) Cognitive dependence on the wearable computer from longer-term use. The hazard is that upon system failure, the user could be at risk (e.g. during a long bike trip when the user might have developed a reliance on a navigation system comprising radar, GPS, etc.). Head mounted displays introduce their own safety issue since they occlude vision in some manner. Again, the amount of occlusion that presents a safety hazard in different environments must be determined through research. Head mounted display manufacturers and system builders must be aware of the safety issue. The results from long term usage of displays are also not well understood. Headaches, fatigue and other undesirable symptoms may result after extensive usage of the displays. Systems that are worn for a lengthy period of time will introduce various discomforts in the wearers. These results are going to vary depending on the age and physical characteristics of the wearer but, again, system designers and manufacturers of the various components must be aware of and take responsibility for the long term effect of using their systems.

- Collaboration

For many tasks, it is important for the wearer to collaborate with other people. For example, a shopper may wish to send an image of a new sofa to a spouse for an opinion, a mechanic may wish to send a picture of a troublesome part to a remote expert for assistance in replacing that part, or an office user may want to share a screen display with a person seated nearby. Thus, a portion of the wearable system consists of image collectors, senders, and displayers. How such functions should be integrated with other functions and with the user interface and how the wearer should interact with remote collaborators are all open questions.

Applications

At the workshop, six different types of applications were discussed: those for the disabled, personal use for day-to-day living, manufacturing, maintenance, emergency medical treatment and training. We now discuss these six application areas in more detail.

Disabled

The type of wearable system a disabled person will wear depends on the type of disability that they have. At the workshop, a system for the blind was demonstrated. This system was designed to help the blind with their global navigation problems. That is, where am I and how do I get to where I want to be. The system had a GPS connection, earphones to alert the wearer as to upcoming changes in direction or leaving the correct route and a planner that enables the wearer to inform the system as to a desired destination and route to that destination.

There was much discussion about the appropriate type of system to accommodate for other handicaps but no one else had any specific system experience to discuss.

Personal

A wearable computer by virtue of always being with the wearer provides the opportunity to enhance individual capabilities. It also provides an opportunity to sense and act on aspects of the wearer not normally available to sensors.

The types of enhancement include those done at the direct behest of the wearer such as accessing a data base with information and those done by agents operating at the indirect behest of the wearer such as recognizing a face and calling up identification information.

The types of actions based on sensing the wearer include: playing music of a particular type in response to mood sensing, health monitoring and reporting, and interrupting the wearer with e-mail and other messages when the wearer is not actively engaged in some other task.

Manufacturing

Data collection and quality control in food processing were discussed. These applications involved tasks which required the operators to use both hands while collecting the desired data. Additionally, the nature of the materials being handle precluded the use of hand based input devices; i.e. food products subject to contamination. Speech was used exclusively with visual and audio user feedback. Wireless RF networking was employed to log the data to a central database in real-time. High level industrial noise (>90db) offered many design challenges for speech input.

Augmented reality manufacturing applications were also presented. That is, the computer system has some mechanism for sensing the wearer's field of view and then overlaying computer generated imagery over the real world being viewed. Thus, for example, assembling wire bundles for aircraft involved overlaying placement of the next wire in the wire bundle on an installation grid or assembling composite components involved overlaying templates over physical molds.

Maintenance

Maintenance applications discussed were not augmented reality but were concerned with delivering and receiving information to or from a maintenance technician. Generally, what was being delivered were repair procedures, schematics and trouble-shooting procedures, and what was being received from the technician was inspection information. One system for automobile repair was speech based, other systems used hand based input devices.

Emergency Medical Treatment

Emergency medical technicians (EMT) use wearable computers to take notes at the site of an accident, to monitor vital signs and transmit them to a hospital in advance of their arrival and to retrieve protocols of treatment. Speech has been used to navigate experimental systems but EMTs operate in very noisy environments and the system has to be able to recognize spoken commands in the presence of loud ambient sounds and stress.

Training

Wearable computers can be used in either classroom based training or on the job training. In the classroom, by having wearable computers that are aware of their location and that can communicate via wireless methods to larger systems, students can, for example, make personal annotations on materials presented in the class. On the job, for another example, manuals and procedures can be fed to students as they are trained to perform those kinds of tasks we have discussed above. The distinction between consulting with a remote expert and consulting with an instructor is very small for a person on the job.

Summary

The fundamental wearable computer issues are those of innovation, invention, design and evaluation. The space of possible future applications is just beginning to become evident, and of the possible future directions, only a small fraction of those have yet been reduced to practice even at the prototype stage.

Neither the wearer community nor the tasks in which they are engaged are homogeneous and so single design solutions will not be optimal. The body as a platform for computation is fundamentally different than a desktop and so different styles of computation should emerge. On the other hand, the body has been used as a platform for computation at least since we began counting on our fingers and so the constraints imposed by making the computation body resident are not surprising.

Because of the newness of wearable computers, many inventions have yet to be made, and many of those made can only be evaluated by indirect means at this point. Thus, on one hand, what we have been discussing in this white paper is the traditional HCI litany of *know your user* and *evaluate your designs*. On the other hand, however, the types of wearers and the possibilities for designs are only now becoming apparent.

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