Encyclopedia of Human Computer Interaction

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Wearable and Mobile Devices

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INTRODUCTION

Information and Communication Technologies, known as ICT, have undergone dramatic changes in the last 25 years. The 1980s was the decade of the Personal Computer (PC), which brought computing into the home and, in an educational setting, into the classroom. The 1990s gave us the World Wide Web (the Web), building on the infrastructure of the Internet, which has revolutionized the availability and delivery of information. In the midst of this information revolution, we are now confronted with a third wave of novel technologies (i.e., mobile and wearable computing), where computing devices already are becoming small enough so that we can carry them around at all times, and, in addition, they have the ability to interact with devices embedded in the environment.

The development of wearable technology is perhaps a logical product of the convergence between the miniaturization of microchips (nanotechnology) and an increasing interest in pervasive computing, where mobility is the main objective. The miniaturization of computers is largely due to the decreasing size of semiconductors and switches; molecular manufacturing will allow for "not only molecular-scale switches but also nanoscale motors, pumps, pipes, machinery that could mimic skin" (Page, 2003, p. 2). This shift in the size of computers has obvious implications for the human-computer interaction introducing the next generation of interfaces. Neil Gershenfeld, the director of the Media Lab's Physics and Media Group, argues, "The world is becoming the interface. Computers as distinguishable devices will disappear as the objects themselves become the means we use to interact with both the physical and the virtual worlds" (Page, 2003, p. 3). Ultimately, this will lead to a move away from desktop user interfaces and toward mobile interfaces and pervasive computing.

BACKGROUND

Mobile computing supports the paradigm of anytime-anywhere access (Perry et al., 2001), meaning that users have continuous access to computing and Web resources at all times and where ever they may be. Used in a wide range of contexts, mobile computing allows:

1. The extension of mobile communications and data access beyond a desktop and static location.
2. Access to electronic resources in situations when a desktop/laptop is not available.
3. Communication with a community of users beyond the spatio/temporal boundaries of the work or home location.
4. The ability to do field work; for example, data collection, experience recording, and notetaking.
5. Location sensing facilities and access to administrative information.

Mobile devices have several limitations due to their small size (form factor) that need to be considered when developing applications:

1. **Small Screen Size:** This can be very limited, for example, on mobile phones. Solutions to this problem necessitate innovative human-computer interaction design.
2. **Limited Performance:** In terms of processor capability, available memory, storage space, and battery life. Such performance issues are

continuously being improved, but to counter this, users' expectations also are growing.

3. **Slow Connectivity:** Relatively slow at the moment for anywhere Internet connectivity; 3G technologies promise to improve the situation. Wireless LAN connectivity, such as 802.11, provides simple and reliable performance for localized communication.

Mobile devices generally support multimodal interfaces, which ease usability within the anytime-anywhere paradigm of computing. Such support should include:

- Pen input and handwriting recognition software.
- Voice input and speech recognition software.
- Touch screen, supporting color, graphics, and audio where necessary.

In order to take advantage of the promise of mobile computing devices, they need to have operating systems support such as:

- A version of Microsoft Windows for mobile devices.
- Linux for mobile devices.
- Palm for PDAs.
- Symbian for mobile phones.

In addition, mobile devices need to support applications-development technologies such as:

- Wireless Application Protocol (WAP), where in the current version content is developed in XHTML, which extends HTML and enforces strict adherence to XML (eXtensible Markup Language).
- J2ME (Sun Java 2 Micro Edition), which is a general platform for programming embedded devices.
- .NET framework, which includes Microsoft's C# language as an alternative to Java.
- NTT DoComo's i-mode, which currently covers almost all of Japan with well over 30 million subscribers. Phones that support i-mode have access to several services such as e-mail, banking, news, train schedules, and maps.

Standard software tools also should be available on mobile devices to support, among other applications:

- E-mail.
- Web browsing and other Web services.
- Document and data handling, including compression software.
- Synchronization of data with other devices.
- Security and authentication.
- Personalization and collaboration agents.
- eLearning content management and delivery, which is normally delivered on mobile devices via its Web services capability.

Apart from the last two, these tools are widely available, although the different platforms are not always compatible. This is not a major problem, since communication occurs through standard Web and e-mail protocols. Current personalization and collaboration tools are based mainly on static profiling, while what is needed is a more dynamic and adaptive approach. There are still outstanding issues regarding content management and delivery of eLearning materials, since these technologies, which we assume will be XML-centric, are still evolving.

HCI AND MOBILE AND WEARABLE DEVICES

This article will highlight some of the central HCI issues regarding the design, development, and use of mobile and wearable devices. Our review pertains to devices such as mobile phones, personal digital assistants (PDAs), and wearable devices, and less to mobile devices such as laptops and tablet PCs that generally are larger in size.

Several main issues regarding the HCI issues of using mobile and wearable devices have been posited in the literature, including contextual concerns (Lumsden & Brewster, 2003; Sun, 2003), limitations of the interface (Brewster, 2002), and their convergence with other technologies and systems. These devices reflect the range of different contexts that mobile and wearable technology can be used for interfacing with data sets, interactive content, and enhanced visual display that augment activities and exploration within physical environments.

Table 1. Summary of a selection of mobile and wearable interaction tools and interfaces

Interaction Tool/Interface Type	Example	Description	Reference
Gestural interfaces	Georgia Tech Gesture toolkit	The Georgia Tech toolkit allows for those developing gesture-based recognition components of larger systems. The toolkit is based upon Cambridge University's voice recognition toolkit and uses hidden Markov models.	Westeyn et al. (2003)
Voice input devices	Wearable Microphone Array (WMA)	The Wearable Microphone Array provides an interface between context aware speech and the wearable computer. The system is specially adapted for mobile use and is worn on a tie or shirt.	Xu et al. (2004)
Wearable orientation interfaces	Wearable orientation system	The wearable orientation system tested three different interfaces: a virtual sonic beacon, speech output, and a shoulder-tapping system. The latter two interfaces were found to be helpful for those with sight impairments.	Ross and Blasch (2002)
Wearable orientation interfaces	CyberJacket and Tourist Guide	The CyberJacket incorporates a tourist guide for allowing visitors to the area to orientate more rapidly. The system incorporates an accelerometer device, a GPS location sensor, a sound card, and a processor with Web browser.	Randell and Muller (2002)
Mobile augmented reality	Outdoor Virtual Reality	Outdoor Virtual Reality combines an HMD, Tinmith-evo5 software architecture, and a tracking device to allow virtual and real objects to be interacted with on the move and outside. The authors have developed two applications from their system: a 3D visualization tool and an outdoor game (ARQuake).	Thomas et al. (2002a).
Audio interfaces	Ensemble	Ensemble uses garments fitted with light sensors, accelerometers, and pressure sensors as an interface for children learning about music. MIDI controllers and electronic musical instruments also are integrated. The system allows the children to explore the relation between actions and sounds.	Andersen (2004)
Smart clothing	WearARM	The WearARM provides computation power with a design that blends into existent clothing, strapping around the arm underneath your clothing. Intended mainly as a research platform, it will be integrated into the MIThrill (see the following).	Anliker et al. (2002)

According to some commentators, "the design of interaction techniques for use with mobile and wearable systems has to address complex contextual concerns" (Lumsden & Brewster, 2003, p. 197). While the physical environment that the mobile user inhabits is constantly changing, there is a host of environmental issues to contend with, including privacy, noise levels, and general interruptions to the flow of communications and data access. While many current wearable systems are built on mobile technology components such as PDAs, these do not always provide the best interfaces for maximizing wearability, relying as they do upon graphical and visual interfaces.

Developers have met this challenge by designing a whole range of new and adapted interfaces in order to provide eyes- and hands- free interaction. A review of some of the recent mobile and wear-

Table 1. Summary of a selection of mobile and wearable interaction tools and interfaces, cont.

Smart clothing	Smart clothing prototype for the Arctic environment	The smart clothing prototype for the Arctic includes a suit with communication, global positioning and navigation, user and environment monitoring, and heating.	Rantanen et al. (2002)
Touch pad interface	Touchpad mouse Wearable computers	The touchpad mouse can be used as a component with other wearable computers (i.e., with wearable computer and HMD). The touchpad can be worn in a number of different positions on the body; however, testing has shown that the preferred place is on the thigh.	Thomas et al. (2002b)
Peephole displays that combine pen input with spatially aware displays	PDAs	Peephole displays that combine pen input with spatially aware displays, enabling navigation through objects that are larger than the screen.	Yee (2003)
Body area computing system	Wearable Unit with Reconfigurable Modules (WURM)	Plessl et al. argue that future wearable computing systems should be regarded as embedded systems and suggest the development of a body area computing system composed of distributed nodes around a central communications network. Sensors are distributed around the body using field-programmable arrays (FPGAs).	Plessl et al. (2003)

able technology interfaces has found the following interaction tools and interfaces (see Table 1).

As these divergent interfaces indicate, there is as yet no preferred interface for wearable technology, and the scope for HCI input into design issues clearly is needed to inform future integrated systems. In addition to providing more mobile and embedded interfaces, other design parameters have attempted to address individual user difficulties inherent in traversing the physical environment while communicating, and some have been aimed specifically at user groups, including those with hearing or sight impairments (Ross & Blasch, 2002).

EXAMPLES OF WEARABLE AND MOBILE DEVICES

Wearable devices are distinctive from other mobile devices by allowing hands-free interaction or by at least minimizing the use of a keyboard or pen input when using the device. This is achieved by devices that are worn on the body, such as a headset that allows voice interaction and a head mounted display that replaces a computer screen. The area of wearable devices is currently a hot research topic with potential applications in many fields (e.g. aiding people with disabilities). In addition to the interfaces that we already have mentioned, we have reviewed three examples of mobile and wearable devices.

The IBM Linux Watch

(www.research.ibm.com/WearableComputing/factsheet.html)

IBM recently has developed a wristwatch computer that they collaboratively are commercializing with Citizen under the name of *WatchPad*. Apart from telling the time, WatchPad supports calendar scheduling, address book functionality, to-do-lists, the ability to send and receive short e-mail messages, Bluetooth wireless connectivity, and wireless access to Web services. WatchPad runs a version of the Linux operating system allowing a very flexible software applications development platform. It is possible to design WatchPad for specific users (e.g., a student's watch could hold various schedules and provide location sensing and messaging capabilities). A recent commercial product with overlapping functionally, called Wrist Net Watch (www.fossil.com/tech), has been developed by Fossil. Current information such as news headlines and weather is delivered in real time to the watch through the MSN Direct service.

Xybernaut Mobile Assistant

(www.xybernaut.com/Solutions/product/mav_product.htm)

This commercial product is the most widely available multi-purpose wearable device currently on the market. It is a lightweight wearable computer with desktop/laptop capabilities, including wireless Web connectivity and e-mail, location sensing, hands-free voice recognition and activation, access to data in various forms, and other PC-compatible software. It has a processor module that can be worn in different ways, a head-mounted display unit, a flat-panel display that is touch-screen activated and allows pen input, and a wrist-strapped mini-keyboard. Xybernaut is currently trialling the use of the mobile assistant in an educational context, concentrating on students with special needs. It allows the student full computing access beyond the classroom, including the ability to do standard computing functions such as calculations, word processing, and multi-media display and, in addition, has continuous Internet connectivity and voice synthesis capabilities. It also supports leisure activities, such as listening to music and playing games.

iButtons

(www.ibutton.com/ibuttons/index.html)

iButtons developed by Dallas Semiconductor Corporation/Maxim currently are being piloted in a range of educational institutions. An iButton is a computer chip enclosed in a durable stainless steel can. Each can of an iButton has a data contact (called the lid) and a ground contact (called the base) that are connected to the chip inside the can. By touching each of the two contacts, it is possible to communicate with an iButton, and iButtons are distinguished from each other by each having a unique identification address. By adding different functionality to the basic iButton (i.e. memory, a real-time clock, security, and temperature sensing), several different products are being offered. There are many applications for this technology, including authentication and access control, eCash, and a range of other services. In educational contexts, these smart buttons allow registration of students as well as access to classrooms, Web pages, and computers.

MIThril: A Platform for Context-Aware Wearable Computing

(www.media.mit.edu/wearables/mithril/)

MIThril is a wearable research platform developed at the MIT Media Lab (DeVaul et al., 2001). Although not a commercial product, MIThril is indicative of the functionality that we can expect in next-generation wearable devices. Apart from the hardware requirements, it includes a wide range of sensors with sufficient computing and communication resources and the support for different kinds of interfaces for user interaction, including a vest. There are also ergonomic requirements that include wearability (i.e. the device should blend with the user's ordinary clothing) and flexibility (i.e., the device should be suitable for a wide range of user behaviors and situations).

As an application of this architecture, a reminder delivery system called Memory Glasses was developed, which acts on user-specified reminders (e.g. "During my next lecture, remind me to give additional examples of the applications of wearable computers") and requires a minimum of the wearer's attention. Memory Glasses uses a proactive reminder system model that takes into account time, location, and the user's current activities based on daily events that can be detected (i.e. entering or leaving an office).

FUTURE TRENDS

Wearable and mobile devices currently are being used in a range of contexts, but they also are being used in conjunction with a range of other technologies that may have implications for the evolution of human-computer interfaces. Possible uses might include the use of wearable and mobile devices for outdoor activities; for example, Cheok, et al. (2004) consider the use of wearable devices in conjunction with game play that links virtual and real spaces (Xu et al., 2003). Wearables also might allow users to explore access to a range of personalized information services integrating access through portal systems, although this might have implications for security and privacy issues (Di Pietro & Mancini, 2003). Continued development in terms of commercial applications currently are being researched, which may lead to more personalized methods of retail ordering and customer tracking. Others have noted the use of wearable technology in conjunction with augmented reality (Piekarski & Thomas, 2004; Thomas et al., 2002a; Xu et al., 2003).

CONCLUSION

At this moment in time, the innovations seem to be progressing at such a rapid pace that often suppliers of these devices are trying to create a new demand for products at a relatively early stage of their development. It is not hard to predict that the technological issues we have touched upon will continue to be addressed and improved. Regarding standards, we expect current ones to evolve in parallel with new developments, but due to the experimental nature of some of these devices, there will be periods where non-standard appliances will be piloted.

Personalization of user interaction is also an important issue, where adaptation to the user behavior is critical, easing the customization of the interface to suit users' specific needs within the context of the device being used (Weld et al., 2003). Advances in machine learning and artificial intelligence on the one hand and information overload on the other have led to a new challenge of building enduring personalized cognitive assistants that adapt to their users by sensing the user's interaction with the environment; it can respond intelligently to a range of scenarios that may not have been encountered previously and also can anticipate what is the next action to be taken (Brachman, 2002).

Finally, it is also important to investigate the social potential and impact of wearable and mobile devices (Kortuem & Segall, 2003) so that collaborative systems can be developed to facilitate and encourage interaction among members of the community. One possible educational application of such a collaborative system may be an interactive learning environment that supports a range of mobile and wearable devices in addition to integrating a range of learning services.

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KEY TERMS

Hands-Free Operation: Allows the user to interact with data and information without the use of hands.

Head-Mounted Displays (HMDs): Visual display units that are worn on the head as in the use of VR systems.

Head-Up Displays (HUPs): Displays of data and information that are superimposed upon the user's field of view.

Mobile Devices: Can include a range of portable devices, including mobile phones and PDAs, but also can include wearable devices, such as HMDs and smart clothing, that incorporate sensors and location tracking devices.

Multimodal Interaction: Uses more than one mode of interaction and often uses visual, auditory, and tactile perceptual channels of interaction.

Pervasive and Context-Aware Computing: Allows mobile devices to affect everyday life in a pervasive and context-specific way.

Wearable Devices: May include microprocessors worn as a wristwatch or as part of clothing.

Wearable Sensors: Can be worn and detected by local computing systems.