❖ **S t e v e M a n n**

Smart Clothing: The Shift to Wearable Computing

Smart clothing—the combination of mobile multimedia, wireless communication, and wearable computing—offers the potential to make personal computers even more personal.

In the early 1980s, when I first experimented with wearable computing and wireless communications, people thought some of the apparatus I wore looked quite strange, so I didn't wear it much; it was both physically and socially awkward. People were shocked by the visceral combination of human and machine. Even later, with the advent of portable and laptop computers, people were still taken aback by the combination of a human wearing a computer—there was something markedly different in the way others perceived a system attached to my body rather than carried in a briefcase. When I did wear it, I basked in a tremendous sense of self-empowerment, for it seemed the computer was more part of me than it was a separate tool.

My wearable computer was not the first with wireless communications. Thomas Bass, in his book *The Eudaemonic Pie*, describes shoe-based computers of the 1970s designed and built by physicists and other researchers in California, for the purpose of assisting them at playing roulette. It was remarkable they were able to design these computer systems to be so unobtrusive as to pass the ultimate test of unobtrusiveness—the casino test—where they would survive the scrutiny of croupiers and pit bosses.

My goals were different: I was more interested in functionality and capability than in concealment, and ended up with a more cumbersome system, although over the years, it has become smaller and lighter to the point I can now wear it for extended periods.

On my hat, an antenna wirelessly connects to the Internet through a network of antennas I've erected on rooftops of various buildings, including the tallest in Cambridge in order to get some degree of connectivity from nearby cities. This gives me Internet access but because the system is experimental, it is down some of the time, so I am not always able to stay online.

Having an Internet-connected computer wired within my clothing has allowed me to read my email via my smart glasses (eyeglasses with miniature sensor array and cathode-ray tube), say, while standing in line at the bank.

The miniature cameras and computer screen inside my eyeglasses provide me with a dual-adaptation space. Unlike the standard multimedia computer, cameras and microphones point where I'm looking, not at me. This provides the computer with my perspective, and permits me to explore some of the more fundamental issues in visual memory and computer-mediated reality. Other sensors such as infrared and radar, enhance and extend my sensory capabilities, allowing me to explore some new concepts in synthetic synesthesia, which might someday be of assistance to the visually challenged. In the future, perhaps we'll become cyborgian—our clothing will significantly enhance our capabilities without requiring any conscious thought or effort.

With the advent of the World-Wide Web, I've explored connectivity of a new form. If you take a look at http://wearcam.org, you may be looking at whatever I am looking at right now. The Wearable Wire-

The author and his wearable multimedia computer/personal visual assistant. The apparatus includes a miniature computer screen and sensor array in the eyeglasses, Internet connection, and a multimedia computer with special-purpose video processing hardware.

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less Webcam has been both an exploration of a new form of personal visual connectivity and a personal imaging system. Personal imaging includes a visual memory prosthetic that serves as a visual sketchpad with which to take notes. A personal imaging system may also be useful as a tool for visual artists and the next generation of photographers.

My wearable system currently has 64MB of RAM, a Pentium 90 processor, and a 1.2GB hard drive. Smart glasses, smart shoes (with an array of sensors that provide information about my footsteps), and smart undergarments electronically sense, for example, my heart rate, skin resistance, and body temperature. Should someone pull out a gun and demand my money, my smart clothing might respond appropriately (video capture/transmission at maximal frame rate, and so forth) by virtue of the sudden increase in heart rate without any increase in physical exertion.

As a personal safety device, ubiquitous use of smart clothing may have the potential to turn the world into a small-town community—a global village—as barriers of time and space fall. However, privacy is indeed an important consideration and part of my inspiration. What I envision is an alternative to the proliferation of Orwellian pole-top surveillance cameras. Government-installed surveillance cameras are typical of many U.K. cities, and coming to U.S. cities soon. (In Baltimore, the government is already installing a large network of video surveillance cameras throughout the city.) I am hoping, however, that instead of asking the government to install cameras everywhere to reduce crime, we might begin wearing cameras. What I envision is more like David Brin's *Earth* than George Orwell's *1984*.

Privacy will also be an important consideration with respect to the various sensors we may choose to wear. For example, smart clothing may some day be interoperable and interconnected, so that it keeps track of our physical condition and allows us to decrypt this information for evaluation by a doctor.

The recent proliferation of wearable computers (such companies as Phoenix Group Inc., CPSI, and Intervision are currently making wearable computers) suggests we're moving in the direction of smart clothing. However, many of the wearable applications envisioned, such as the land warrior (military), the intelligent maintenance aid, or various applications in the workplace [2] would be better described as smart uniforms. A smart uniform can be issued to a soldier or employee at the start of a job, and then taken away after the job is completed.

There is a fundamental difference in the perception people have about their own clothing as compared to an issued uniform. Although people can become quite familiar with their uniforms, whether worn in the military, certain workplaces, or schools, the individuality of personal clothing, and the pleasures associated with its selection and wearing, should be extended to computing. The full power and enjoyment of this synergy between human and machine will be realized only when the computer is owned, operated, and controlled by the wearer, giving rise to truly personal computing. Examples of wearable technology at the extreme opposite to the personal wearable are ID transponders that have been rejected by many employees, and the monitoring devices attached to some criminals [3].

These devices are owned, operated, and controlled by a remote entity; some have the capability to provide the wearer with an electrical corrective signal (euphemism for electric shock) when the wearer does something against the will of the entity that controls the system (e.g., ventures outside a prescribed boundary). This prospect is as Orwellian as pole-top surveillance cameras. I hope we don't see a future in which people (such as employees of a particular company) are required to wear smart clothing so a manager can see or record exactly what any particular employee does at any time.

Smart clothing has the potential to provide a very intimate form of interaction with the wearer, as it exists within the wearer's personal space. As such, there is both the danger it could violate this personal space, and offer the safety and capability to provide the wearer greater control. I do foresee that like the cellular telephone, pager, pocket calculator, notebook computer, pocket organizer, and wristwatch, eventually wearable computer systems will be owned, operated, and controlled by the wearer—much like one's own clothes. ◰

References
1. Bass, T. *The Eudaemonic Pie.* Houghton Mifflin Company, Boston, 1985.
2. Finger, S., et al. Rapid design and manufacture of wearable computers. *Commun. ACM 39,* 2 (Feb. 1996), 63–67.
3. Hosher, J., Sennott, J., and Winkler, M. Keeping tabs on criminals. *IEEE Spec.* (Feb. 1995), 26–32.

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