Miniature computers built into clothes, shoes and eyeglasses may become the "smartest" new fashion accessories

Wearable Intelligence

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INTELLIGENT CLOTHES were recently displayed at a fashion show at the Massachusetts Institute of Technology Media Lab. At the left, a model wears a television reporter's outfit, equipped with a video camera in her glove and a heads-up display in her glasses.

by Alex P. Pentland

Research on intelligence is mostly about investigating how brains work or building intelligent machines or creating "smart" environments such as a house that can identify and track its occupants. But what about making people smarter? To accomplish this goal, one can consider biochemistry or bioimplants, but the easiest way to improve intelligence is by augmenting the items we wear all the time—glasses, wristwatches, clothes and shoes—with miniature computers, video displays, cameras and microphones. These high-tech "wearables," which are being developed at the Massachusetts Institute of Technology Media Laboratory, can extend one's senses, improve memory, aid the wearer's social life and even help him or her stay calm and collected.

The idea of increasing intelligence with wearable devices is very old. English physicist Robert Hooke wrote in 1665 (in the preface to *Micrographia*): "The next care to be taken, in respect of the Senses, is a supplying of their infirmities with Instruments, and as it were, the adding of artificial Organs to the natural.... And as Glasses have highly promoted our seeing ... there may be found many mechanical inventions to improve our other senses of hearing, smelling, tasting and touching."

One must draw a distinction between wearable devices and those that are merely

portable, the classic example being the pocket watch and wristwatch. The difference is simple: you have to pull out the pocket watch and open it to see the time, whereas the wristwatch enables you to see the time instantly, even while working with both hands. Although this may seem like a minor difference, it greatly affects how you use the device and how completely it is integrated into your life. Watches, eyeglasses and radios have all evolved from handheld portable versions to wearable items, and many of today's portables are destined to become tomorrow's wearables.

Electronic devices are beginning to make the transition from portable to wearable. There are now wristwatches that contain medical monitors and pagers; eyeglasses with embedded computer displays that only the user can see; vests, belts and watches with computers inside them; and cell phones and pagers that come with Internet connections and tiny teleconferencing cameras.

Equipped with wearable computers and other devices, people can conveniently check messages or finish a presentation while sitting on the subway or waiting in line at a bank. Even more important, they can also ignore these machines while attending to other affairs. Operating portable devices, in contrast, often requires your full attention and both hands. You have to stop everything you are doing and concentrate on the device. To appreciate how inconvenient this situation is, imagine having human aides (instead of electronic aids) who grabbed your hands and shouted in your face every time they had something to say.

Wearable devices can be much less disruptive, and people relate to them differently than they do to other tools. Something that's with you all the time can change the sense of who you are and what you can do. As we adapt to wearable devices and shape our personal habits around them, over time the culture as a whole will shift to incorporate them.

Hardware That's Made to Wear

Psychological studies show the validity of the phrase "the clothes make the man." Our self-perception and self-confidence can indeed change with our clothes. The same is true for any constantly available device—and not always for the better. Those of us who are continually "on call" via a pager know how fundamentally these tools can alter one's life. The personal effects of many information and communications technologies recall Marshall McLuhan's dictum, "the medium is the message"—that is, the way in which a new technology changes our way of life can be more important than the information it conveys. But wearables are more personal than traditional communications tools because they are a constant part of one's physical presence: they are not only part of what you wear but also part of who you are.

In the near future, the trend-setting professional may wear several small devices, perhaps literally built into their clothes. A person "dressed for success" in this manner may appear to have a fantastic memory, to be amazingly knowledgeable and to have powers of detection and deduction second only to Sherlock Holmes. These wearable intelligence devices can enhance one's "memory" by providing instant access to books, digitized maps, calendars and various databases; providing wireless connections to the Internet and e-mail; and boosting one's awareness with various sensors.

The hardware technology for this scenario has already been developed at research universities such as Carnegie Mellon, the Georgia Institute of Technology and the M.I.T. Media Laboratory, at large companies such as IBM, Toshiba and Motorola, and at start-up companies such as MicroOptical in Boston and the Flexible PC Company in Northfield, Minn. In my "wearables closet" I have glasses with a private, full-resolution computer display; a health monitor in a watch that records my temperature, heart rate and blood pressure; a computer-in-a-belt with a wireless Internet connection; a lapel pin that doubles as a camera and microphone; and a touchpad or keyboard literally sewn into a jacket. Soon there may be no need for batteries because sufficient power can be generated by harvesting the excess energy in normal walking (for example, by putting piezoelectric materials in shoes that generate electricity when compressed). Connecting wires might also become unnecessary by making use of conductive fibers woven into clothes or by transmitting small amounts of power via radio signals and skin conduction—all of which have been demonstrated at the Media Lab.

It is too early to tell which approaches to wearable design will prove popular. Some people, for example, may be comfortable with head-mounted video displays; others may find them unwieldy. Some may like the feel of headsets similar to those used by telephone operators; others may prefer less conspicuous audio and speech interfaces. The devices can be built in many ways, and it will take a fashion and style battle to determine what people really want to buy. The Media Lab, however, is not taking a passive attitude toward this issue. On the contrary, several years ago I initiated a collaboration with some of the world's most famous design schools to see what future wearable fashion would look like. Some tantalizing visions have already emerged from this effort.

As with most new technologies, wearables will probably make their biggest inroads in specialized tasks before becoming widely adopted by the gener-

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VEST WORN by a model is designed to translate a person's speech into another language. Microphones on the front of the vest record the voice, and speakers on the shoulders broadcast the translation.

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RING WITH BAR-CODE READER is already being sold for use in warehouses and loading docks. The device allows workers to identify the contents of a carton and to read shipping and handling instructions.

al public. Wall Street traders could rely on the devices for information needed to make quick decisions on the trading floor. Doctors could use them to store medical records and take pictures and notes. Industrial inspectors and scientists working in the field could jot down their observations while walking around. Repair workers could obtain assistance in the midst of a complicated job.

Thousands of Federal Express delivery people are now equipped with wearables so that the company can better coordinate its efforts around the world. Another company, Symbols Technologies in Holtsville, N.Y., makes a wearable device in the form of a ring with a built-in Universal Product Code (UPC) reader and computer display. When pointed at any product that has a UPC bar code, the ring can automatically pull up consumer reviews, instruction manuals and other information about the product.

Tailoring for a Better Fit

Although their potential is vast, many of these devices suffer from a common problem: they are mostly oblivious to you and your situation. They do not know what information is relevant to you personally or when it is socially appropriate to "chime in." The goal in solving this problem is to make electronic aids that behave like a well-trained butler. They should be aware of the user's situation and preferences, so they know what actions are appropriate and desirable—a task I call "situation awareness." They should also make relevant information available before the user asks for it and without forcing it on the user—a task I call "anticipation and availability."

To enhance situation awareness, the wearable device can employ sensors of various types to determine where the user is and what he or she is doing. The device can also monitor the user's choices and build a model of his or her preferences. A person can actively train the computer by saying, "Yes, that was a good choice; show me more," or "No, never suggest country music to me." The models can also work solely by statistical means, gradually compiling information about the user's likes and dislikes. (Firefly Network, a company started by my Media Lab colleagues, takes this approach, recommending books or movies to people depending on how their tastes match the profiles of millions of other users.)

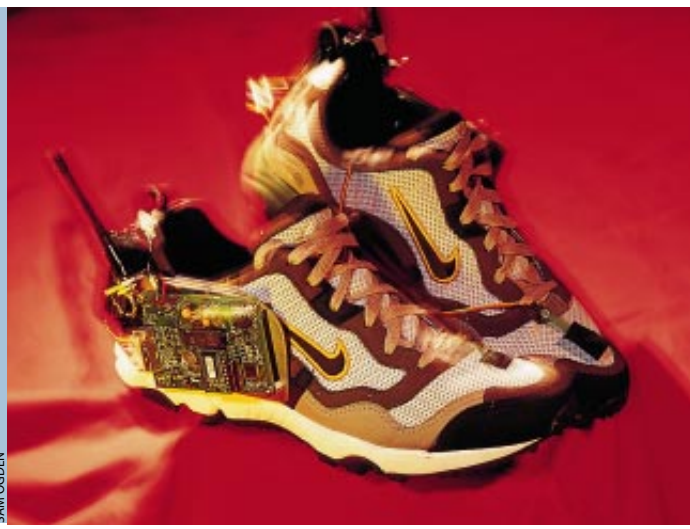
For anticipation and availability, the wearable device can take a few key facts about the user's situation to prompt searches through a digital database or the World Wide Web. The information obtained in this manner is then presented in an accessible, secondary display outside the user's main focus of attention.

A good example of memory augmentation devices that use these design principles are electronic navigation aids relying on Global Positioning System (GPS) satellites. The typical navigation aid has a display that constantly shows one's current position on a map and indicates with an arrow how to reach the stated destination. There are handheld versions for hikers and plug-ins for laptops, but most are currently found in automobiles.

The promise of never being lost is a strong selling point for these aids, but they can do much more: for example, the devices can use your current location to call up information about nearby landmarks. You don't have to type in queries to find the local restaurants or gas stations; everything is retrieved on the basis of your present position. The ease and utility of such automatic indexing is making navigation aids a huge commercial success.

A wearable version of this device is now being manufactured by Motorola with advice from my students and me. The U.S. Army will soon be field-testing 50 of these GPS navigation and communications systems on its troops and plans to outfit tens of thousands of soldiers with the technology in the next few years. Of course, the same wearable aids can be used just as easily by tourists. The system would include a GPS sensor, a wireless connection to a digital database (such as the Web), a microphone and a digital camera. When you visit a tourist attraction, the device could show you the historical facts about the site and give you directions to the next stop on your itinerary. You could then wander around at your leisure with the wearable equivalent of a personalized tour guide.

DANCING SHOES developed by Joe Paradiso, a scientist at the M.I.T. Media Lab, convert dance steps into music. The shoes could also inform runners of a kink in their stride.



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SOCIAL WEARABLES can be used as icebreakers at parties. The devices flash infrared light to communicate the names of their users and any information they would like to share.

This type of system relies on database "filters" and "agents" that use information about the wearer's situation—for example, his or her location and the time of day—to fetch pertinent data and to label the images, text and sounds that the wearer might find interesting. Although software agents will never be able to magically anticipate our desires, they can discern something about our patterns from statistical analyses. For instance, depending on the user's instructions, today's tools can bring to one's immediate attention e-mail from a spouse or boss and save the rest for future perusal.

Although it is impossible to say exactly where wearable intelligence technology is heading, I suspect the trend will be toward devices with greater situation awareness, achieved in part by using additional sensors such as cameras and microphones. My research, for instance, focuses on building wearables that attempt to see what the user sees and hear what the user hears. My idea is that you can't know what people might be interested in unless you know what they are hearing and seeing.

In essence, I want to give the software agents eyes and ears so that they can better understand—and thus better help—their human users. As the tools my students and I build become more reliable, and people become more comfortable with them, the agents could be allowed greater initiative. I expect that eventually many of the small tasks that complicate our lives will be delegated to such agents.

To this end, my research group has built wearables with small cameras mounted on the user's hat or glasses, which employ computer vision techniques to recognize what the person is looking at, without the need for bar codes or other tags. Once the computer knows what the person is looking at, it automatically gathers information about that object. When you meet someone, the computer can run a face-recognition program on the camera image to remind you of the person's name and other noteworthy facts. Alternatively, this computer-camera wearable can function as an expert adviser, analyzing the layout of balls on a pool table, for example, and identifying the best available shot.

A wearable with a downward-looking camera provides another interesting source of situation awareness, because it can see what you're doing and observe your hand gestures. One version of this system reads American Sign Language and converts it into audible English. Another version can distinguish between activities such as handshakes, typing and driving, so that it can tailor its information retrieval to fit the current activity. (Technology similar to that used for speech recognition can be used to identify patterns of motion rather than patterns of sound.)

Other kinds of situation awareness can be achieved with audio input. We have built wearables that know when you and another person are talking, so that they don't interrupt. Although the system is not 100 percent accurate, we plan to make it better by using a camera that can determine whether sounds are coming from you or someone you're talking with, rather than from anybody in the vicinity.

We have also built devices that recognize what you are saying and then translate your phrases (albeit crudely) into another language. This system could be helpful for travelers and for people with serious speech impediments. Currently the technology works only for

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AFFECTIVE WEARABLE monitors the stress of Jennifer Healey, a graduate student at the M.I.T. Media Lab, by measuring skin conductivity and temperature. The data can be downloaded to a PalmPilot, which can display the user's vital signs.

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POOL-PLAYING WEARABLE includes a head-mounted camera that records the position of the balls on the pool table. Specially designed software analyzes the possible shots and identifies the easiest one. A heads-up display (inset) *helps graduate student Tony Jebara line up the shot.*

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SIGN-LANGUAGE TRANSLATOR is demonstrated by its developer, Thad Starner, one of the Media Lab's original "cyborgs." The video camera on his hat records his hand gestures, and motion-recognition software converts the signs into English. In the photograph Starner is signing the word "bicycle."

a user who has "trained" the system. Simultaneous translation of a two-way conversation, unfortunately, is still a distant dream.

Wearable items can offer important social benefits, helping us recognize people we might otherwise ignore or providing new ways for strangers to find common ground. In addition to assisting our memory, wearable intelligence aids can also augment our other talents and abilities in such areas as music, dance and athletics. One device (called "dancing shoes") converts dance steps into music; another can assist people with their baseball swings.

The Body Electric

Wearable medical monitors should become increasingly useful in the future. Today your doctor gets a "snapshot" of your physical condition about once a year, which is far too infrequent to catch incipient diseases. The failure to do more regular health monitoring is particularly problematic for the elderly, whose condition can change quite quickly. Even more troubling is the fact that current medical specialists cannot explain how most problems develop, because they only get to see people when something has gone wrong.

Yet it is now possible to build small devices that continuously monitor a wide range of vital signs. My students and I are working with the Center for Future Health at the University of Rochester to develop such medically oriented wearables, including early-warning systems for people with high-risk medical problems and "elder care" wearables that will help keep seniors out of nursing homes. Another simple but important application for medical wearables is to give people feedback about their alertness and stress level—an approach currently under study at the Media Lab by Rosalind W. Picard's "affective wearables" group.

A system that constantly tracks one's vital signs could yield helpful information, but it could also overwhelm the wearer with raw data, making it difficult to reach any decision. Similar concerns can be raised about wearable intelligence systems in general, which could potentially swamp users with too much data and leave them feeling burned out from the lack of "down time." The devices might also encourage people to retreat further into themselves and their machines, leading to greater social isolation.

I agree that poorly designed wearables could cause such problems. But information overload and social disruption are usually not caused by too much information or connectivity per se. After all, business and government leaders have always dealt with huge amounts of information and organizations with thousands of people. Instead it seems to me that most difficulties arise when information and communications are not properly integrated into our daily routine.

To avoid these problems, we need wearable devices that are organized around the pattern of our lives, rather than organizing our lives around them. I think we can accomplish this goal by making wearable devices that are sufficiently aware of their surroundings and the likes and dislikes of their users.

It should be noted that when books first became cheap and portable items, many feared that family life and popular

culture would disintegrate, as people spent more time reading and less time talking. The impacts of eyeglasses and watches were also hotly debated in their time. But despite gloomy predictions, books, watches and glasses are now an accepted part of our lives. We've grown accustomed to them, and I think we are considerably better off, even though we are different people because of them. Wearable intelligence aids will cause similar adjustments.

The great advantage of wearable devices is that they can be with you constantly, serving as a mental aid that is part of your body and part of your everyday life. If we can endow these tools with sufficient situation awareness to make them a help rather than a hindrance, they offer the promise of enhancing human intelligence in a seamless and enjoyable way. SA

About the Author

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ALEX P. PENTLAND is the academic head of the M.I.T. Media Laboratory, Toshiba Professor of Media Arts and Sciences at M.I.T. and external director of the Center for Future Health at the University of Rochester. He is a founder of the IEEE Wearable Computing technical area and has published over 200 papers in the fields of wearable computing, machine and human vision, human-machine interface, computer graphics and artificial intelligence. *Newsweek* magazine recently named him one of the 100 Americans most likely to shape the next century. "I got into this field because I've always been unhappy with traditional theories of intelligence," he says. "There are different aspects of human intelligence, each of which can be augmented."

In addition to developing wearable devices, Pentland enjoys exploring their use in dance, fashion and other artistic endeavors. In recent years he has organized wearables dance performances in Hollywood, wearables fashion shows in Paris, Tokyo and Boston, and wearables performance pieces at various sites around the world. He would like to thank the Media Lab's former and current graduate students—particularly Thad Starner, Bradley Rhodes and Steve Mann—and colleagues Neil Gershenfeld, Mike Hawley, Pattie Maes, Joe Paradiso, Alice Pentland, Rosalind Picard and Mitch Resnick.

MACHINE INTELLIGENCE

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Information on wearable devices is available at www.media.mit.edu/wearables on the World Wide Web.