

Connecting Virtual and Visceral:

An Introduction to the Evolution of Wearable Computers for Industrial Designers

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1. Introduction

Wearable computing has become a field of its own, focused on systems that monitor people's health, connect them to others, augment their physical capabilities, deliver interactive entertainment, and support other networked activities. Though currently led by computer scientists, human interaction specialists, and engineers, this rapidly expanding field could benefit from the expertise of industrial designers. Industrial design can contribute skills and knowledge to optimize the design for human experience, cultural acceptance, and manufacturability. To date, however, industrial design rarely shows up in any search of publications in the wearable computing field. For example, in the Proceedings of the Ninth IEEE International Symposium on Wearable Computers in 2005, 46 papers were published, two of which document a design investigationⁱ. In each of those cases, the focus was on fashion design.

This paper is intended for the industrial design educator and industrial designer, providing information about the field of wearable computing, highlighting exciting advances in connecting people to remote information, places and people. It identifies the areas in which industrial design skills and knowledge could play a significant role in design development.

2. History

In his brief history of wearable computing, Bradley Rhodes points to the 11th-century technological advance that led to the development of eyeglasses.ⁱⁱ He says the "earliest recorded mention of eyeglasses" referred to handheld reading stones, actually complex-shaped lenses, used to magnify images. They eventually developed into the hands-free eyeglasses we wear today. As lens technology improved over time, the popularity of glasses for augmenting a variety of visual impairments led to demands for other design improvements. This is an example of how good design principles applied to an increasingly accessible technology can contribute to its general acceptance. Factors such as the use of appropriate materials, comfort, safety, durability, visual language (style), affordability, and efficient manufacturing are key to a product's success. Indeed, today many industrial designers are employed in the design of eyewear.

The first appearance of the watch in the 16th century involved complicated human-centered design issues that can also be seen as precursors for the design of wearable computers. The watch is "an example of a technology that evolved physically from immobile to portable to wearable, that employed a variety of user interfaces, and that revolutionized cultural conceptions: Time-keeping."ⁱⁱⁱ In his paper on parallels in the development of the watch and the wearable computer, Thomas Martin focuses on three significant design issues: wearability, user interface and cultural impact. He sites examples of watches worn as balls on necklaces, as pocket watches on neck or belt chains, as brooches, as rings, and finally as wristwatches. Like early watchmakers, who fit their clockworks into the common musk balls, early [contemporary] wearable computer builders fit their designs into common fashion accessories.^{iv} He points out that many of today's wearable computers are worn on belts or in backpacks, which are the common fashion accessories on campuses where the design of wearable computing devices is emerging. As technology has become smaller and more affordable, researchers are poised to make the leap to produce their inventions in larger quantities. The industrial designer can play a role in evolving the invention out of the backpack and onto the body, optimizing the devices for a wider range of users.

It can be seen that the escalating miniaturization of components in the latter half of the 20th century led to more diverse applications.

At MIT, Ed Thorpe and Claude Shannon invented a wearable timing device as early as 1961...Slightly bigger than a wristwatch, it was a concealed time calculation apparatus intended to predict roulette wheels...Herbert Upton, in 1967, designed an eyeglass display as an aid for lip-reading. Ten years later, in 1977, C. C. Collins developed a

wearable camera-to-tactile vest for the blind... And, of course, in what would prove to be a landmark move with implications that are still being wrestled with today, 1979 saw the arrival of the Walkman from Sony, the first commercial wearable entertainment device.^v

The Walkman paved the way for the iPod and other wearable MP3 players whose enormous popularity is due, in part, to design excellence. In 2007, iPod products won five of the iF (International Forum) gold selection product design awards.^{vi}

The United States Department of Defense has led the way in developing wearable computing applications to monitor and communicate with soldiers in the field. These have also been developed for industrial use over the last ten years; for the fire service, the police, security guards, fast-food outlets, convenience stores, maintenance work, and construction.^{vii} At the 2004 International Symposium on Wearable Computers, this author was the only person in a packed elevator who was not wearing a head-mounted display attached to a hip-mounted computer! The future is upon us, and wearable computing technologies are consumer commodities with design implications. As the success of the iPod demonstrates, industrial designers can play a key role in giving emerging wearable inventions the kind of “personality” that leads to everyday acceptance.

3. Context

Wearable computing refers to a system of networked devices incorporated on or in a person’s body that is continually processing information. A wearable computer is often described as a system that is:

- unobtrusive to the point of being an integral part of the users clothing,
- portable while operational and always on,
- equipped with a hands free or nearly hands free user interface,
- able to augment the users perception of the reality (e.g., merge a computer-generated image with the users view of the world using a see-through display),
- context and environment sensing (knows what the user does and what is happening around him) and
- able to act on the users behalf even without his knowledge and get his attention whenever required^{viii}

In their seminal paper, “Design for Wearability”, Francine Gemperle and her peers at Carnegie Mellon University report on their seven-year hands-on field study developing mobile and wearable computer systems for a variety of industrial, commercial, and military applications.^{ix} They provide important design guidelines that support the previously described features of wearable computer systems. Their paper was significantly different than the mostly technical papers being published in the field in 1998 and even today, which was a consequence of involving industrial designers in this research from the beginning. In fact, two of the contributing authors are Principals in BodyMedia, a company that bills itself as “a world leader in the design and development of wearable body monitoring products and services.”^x Their guidelines can be divided into two categories as follows:

- i. Wearability in relation to the human body
 - identifying areas on the body that allow for unobtrusive placement of wearable devices.
 - using a “humanistic” form language for the devices to conform to body surfaces.
 - placing the devices in areas that allow for free body movement.
 - designing forms to fit within a person’s intimate space “bubble” to increase the perception of it belonging on the body.
 - allowing for a range of fit through a combination of flexible and rigid areas.
 - focusing on comfortable and adjustable attachments.
- ii. Wearability in relation to the system
 - Identifying constraints based on what the devices contain.
 - Determining the optimal distribution of weight within the device and on the body.
 - Designing for the best possible usability access.
 - Keeping sensory interaction simple and intuitive.
 - Allowing for thermal characteristics that enable the body to breathe.
 - Sensitivity to aesthetics dictated by culture and context.

- Studying the long-term physiological effects of wearing systems.^{xi}

4. Current Research

Today, there are a handful of researchers who have used themselves as guinea pigs to study the long-term effects of wearing computer systems. The most notable is Professor Steve Mann of the University of Toronto, who has been commonly referred to as the father, now grandfather, of wearable computing. When this author asked him if he had worked with industrial designers in any of his wearable computing projects, he replied that he would be interested in collaboration with industrial designers and made reference to an article his team had published in an Italian industrial design publication. He began designing his wearable computing system as a teenager in the 1970s, continued this work as a student at MIT, and today is famous for the increasingly sophisticated evolution of his “WearComp” personal imaging apparatus which includes a “data processing system attached to the body, with one or more input and output devices.”^{xii}

Thanks to “WearComp,” an increasingly inconspicuous and elegant “wearable computer” of his own design, Mann is perpetually in contact with the Internet, communicating when he wants to by tapping messages on a pocket device and better by projecting the view from his eye-level camera onto the Web. His senses of sight and hearing (though not yet, one gathers, smell, taste or touch) are thus mediated and enhanced: want to see a face more clearly from a distance? Just zoom in! Hate Coke ads? Get the computer to erase them. Want an instant replay in slow motion. He can get that too, with enough control to read the markings on the spinning wheels of a passing car...And all the while he has the power of the internet literally at his fingertips, so that he can not only consult a dictionary, look up arcane facts to win an argument, but also bring the word to bear witness to what he sees.^{xiii}

Another pioneer of distributed body-worn computing systems is Dr. Thad Starner, Director of the Contextual Computing Group at Georgia Tech. He also studied at MIT’s Media Lab, and along with Steve Mann has worn his system continuously for over twenty years. At a workshop in 2004, Starner explained that his own wearable system was initially a memory prosthetic, which he began wearing as a student at MIT so he could be connected to enough information to enable him to keep up with his peers!^{xiv} Like Mann, his research in this area is prolific: it includes devices for sign language, augmented reality, human-generated power for mobile electronics, and security applications for face and handwriting recognition. In 2004, when this author asked him if he worked with the industrial designers at Georgia Tech, he replied that they were preparing to do so. Apparently, there is some industrial design student involvement with his Contextual Computing Group, but the collaboration has been very slow to develop.

While both Starner and Mann have learned a great deal through applied research using themselves as guinea pigs, industrial design has a long history of validating design concepts with multiple sample users and iterative prototypes that are quick and easy to build (and discard). This expertise can assist the technical expert/guinea pigs in rapidly developing accessible and affordable products.

Professor Joanna Berzowska, a graduate of the Tangible Media Group at the MIT Media Lab, who is now at Concordia University in Montreal, has a team of students working on electronic textiles and responsive garments. The garments themselves capture, reply, and/or react to social or cultural situations, combining electronic components with fashion design.^{xv} Her work is still in the one-of-a-kind personal expression style and serves as a philosophic platform for exploring cultural experiences. However, in the case of products using proven technologies, industrial design has been recognized for its significant contribution. In the 2006 IDEA (International Design Excellence Award) consumer product category, Motorola and Burton were bronze winners for their Audex jacket series with “integrated stereo speakers in the hood, a microphone and battery compartment embedded in an inside pocket and a control panel on the sleeve that allows remote operation of a phone and iPod”.^{xvi}

5. Components and Wearable Systems

The United States military Land Warrior and Future Warrior programs have advanced the concept of wearable computing for the soldier in the field. “The warrior is becoming more and more electronic”.^{xvii}

That bodes well for the continued improvement of components for wearable computing devices. For example, the size and weight of the power supply can restrict the length of time a system can be worn and its position on the body. A marriage of batteries with fuel cells might provide a more diversified source of power. The battery could be used only occasionally, to handle start-ups and heavy power loads, while the fuel cell recharges the battery and provides steady-state power.^{xviii}

Depending on the application, there is much more than power to making a wearable system technically functional. At the heart of every wearable system is a processor, which has some sort of input device(s) and some sort of output device(s). Many of the wearable applications for the military, health care, and communications applications are networked and require technologies to enable connectivity. The miniaturization and reduction in the cost of digital memory (hard drives, recordable DVDs, and flash cards), digital cameras, personal digital assistants, and other digital accessories enable us to capture and store a constantly growing amount of personal data.^{xix}

In addition, the vast array of sensors can provide a wide range of capabilities: accelerometers for determining speed and direction of motion (useful for devices for seniors to determine if they have fallen), cameras to capture images for immediate or future transmission (useful for head mounted displays such as Thad Starner's Sign Language Recognizer), acoustic sensors for picking up sound, and galvanic skin response sensors for identifying changes in skin conductivity or stress. Other sensors are magnetic, pressure, altimeters, compass, and gyroscope (for orientation). But it is important to note that good design research can simplify the number and type of sensors in a wearable system. For example, Rita Di Cesare, in her fourth-year major industrial design project at Carleton University started working on a wearable biofeedback garment for stress reduction. Initial concepts considered the inclusion of sensors to measure heat flow, galvanic skin response, skin temperature, heartbeat, and blood pulse rate. The final concept reduced this to a heart rate monitor, vibrating pods, and an integrated information display. The simplification evolved over two months of usability testing, consultations with systems and computer engineers, and iterative prototyping.^{xx} The industrial design goal was to make an affordable, easy to use garment that would fit and improve the user's daily experience.

Another fourth-year major industrial design project was a pediatric asthma monitoring system designed by Steve Gervais (Figure 1). It consists of an asthma symptom monitor worn by the child and an "asthma companion" that communicates with both parent and child. The child's symptom monitor contains a piezoelectric film contact microphone to pick up lung sounds, a coin cell battery, and a Bluetooth module. The Asthma companion contains a lithium rechargeable battery and a Bluetooth module.^{xxi} Design thinking was required to identify the form and interaction attributes that would be acceptable across generations.

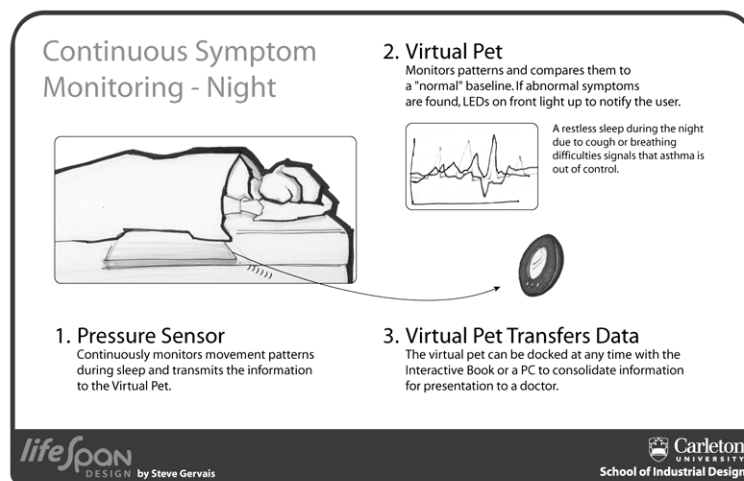


Figure 1. Early design thinking about the Asthma Companion by Steve Gervais.

Sensors and conductive textiles provided the opportunity to design a two-part wearable system for monitoring premature infants when they are first brought home from hospital. A soft infant wearable designed by Laura Waggott monitors heart rate, respiration and audio, and transmits that information to the parent's wearable device (Figure 2). The parent is in touch with the infant's status anywhere in the home, and can access information relating to the baby's care and well-being. Initial concepts which included monitoring involving video, vital signs, and auditory data capture were greatly simplified after usability testing and iterative prototyping determined how much information the parent needs to know without becoming alarmed. The final concept included an "electro-active" textile heart rate sensor, an accelerometer to monitor respiration rate and a microphone to monitor crying.^{xxii}

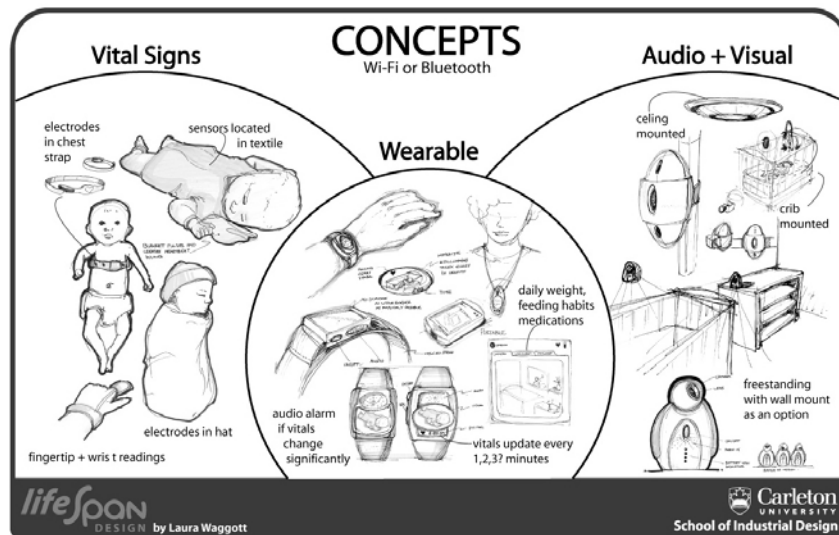


Figure 2. Early scenarios and system concepts for Infant Monitoring by Laura Waggott.

In each of these projects, the user experience determined what to monitor, measure, transmit, store, and communicate. There has to be a good reason to use technology, not just because it exists. Alan Cooper admonishes, "The high-tech industry has inadvertently put programmers and engineers in charge, so their hard-to-use engineering culture dominates."^{xxiii} Industrial design can mediate between the technical

functionality of wearable computing systems and the design features that contribute to useful and affordable products.

6. Ethical Considerations

Some of the challenges in the design and development of devices that not only monitor situations such as the ones described here, but also transmit and store that data are related to privacy of information. Who has access to it? Where is it stored? How will it be used? How long will it remain in cyberspace? Other concerns address complexity and reliance. What if it is too hard to use or learn to use? How can it become affordable? What if people become too dependent on the technology? How is it disposed of when the technology fails or becomes out of date?

At MIT these issues have been of concern since the 1980s. Neil Gershenfeld, leader of the Physics and Media Group at MIT, offers his perspective;

Our legal system is already straining to cope with the unexpected implications of connecting smart distributed systems. Establishing technological rights cannot happen by central command; it must happen by changing the expectations of both the designers and users of the new technology.^{xxiv}

Steve Mann also identifies the challenges that can be predicted for wearable computing. He says, “the beeper, the cellular phone, the Palm Pilot--all these innovations can be viewed not just in terms of their liberating possibilities, but also in terms of their capacity to reduce freedom”. He goes on to say that it is conceivable that “the wearable computer [might] be misused and become part of the apparatus of control.”^{xxv} Industrial designers can surely respond to Mann’s warning that the wearer should have autonomy over the technology he or she is wearing. The fundamental issue in wearable computing is that of personal empowerment, through the equipment’s ability to provide the individual with a personalized, customizable information space owned, operated, and controlled by the wearer.^{xxvi}

7. Conclusions

In summary, wearable computing has evolved from using technology to augment experience, to augmenting and processing experiences. Computing has evolved from the machine on the desktop to a networked system of components distributed on the body. This evolution has given rise to new and different design issues such as the simplification of complex technical capabilities, sharing and expansion of interfaces, and the integration of the system with or on the body. Currently computer scientists, human interaction specialists, and engineers who are expert at making the technology work and at interpreting how it should work for people are taking the lead in the field of wearable computing.

In his book, *The Inmates Are Running the Asylum: Why High-Tech Products Drive Us Crazy and How to Restore the Sanity*, Alan Cooper makes a case for interaction designers who focus “on the way users see and interact with software-based products”.^{xxvii} He praises industrial designers for being skilled at “creating objects in three-dimensions that fit your vision, your body, and—especially--your hands.” But he goes on to point out that industrial designers are not trained to “satisfy the demands of cognitive friction, nor to work with software engineers.”^{xxviii}

It’s time to change that perception, and bring the skills that were developed in the industrial design profession, as Bill Buxton points out in his new book, *Sketching User Experiences: Getting the Design Right and the Right Design*.^{xxix} He provides examples of good industrial design processes that will improve the user experience such as design research, iterative concept development, sketching, sketch prototyping, iterative testing, definitive design definition, leading to a holistic design concept that integrates user experiences, capabilities and desires with the affordances of technology.

The field of wearable computing is expanding and the time is ripe for industrial designers to connect with the researchers and companies who are leading the way, and to demonstrate that Industrial Design can add skills and knowledge in the area of optimizing the design for human experience, for the human body, for cultural acceptance, for aesthetic sophistication, and for manufacturability. Researchers, who have spent years refining the technical capabilities of their one-of-a-kind prototypes, are not experts at

optimizing products for commercialization. That falls into the realm of industrial design and presents a timely opportunity for industrial designers to collaborate in the design of wearable devices.

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