Wearable Computing From Jewels to Joules

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The wearable devices we can purchase today represent generations of improvements in the form factor, power requirements, and performance of components, as well as a growing understanding of issues related to the user experience. We've reached a point where hundreds of companies, both new and old, now believe that wearable devices and the infrastructure to support them are practical and achievable.

Just in the time we've been preparing this issue, scores of companies have announced new wearable products and applications, and researchers around the world have published new technologies for improving the usability and functionality of the devices. It's an exciting time to be working in this area, especially for those who enjoy the unpredictability of designing technology that interacts directly with people. Such interaction renders answers to seemingly simple product questions elusive.

Dealing with People

One of the most pressing current questions for designers is whether they have created a product that people will continue to wear after the initial novelty is no longer a factor. It's hard to predict what people will actually wear, even for special-purpose wearable devices that demonstrably solve a particular problem for their users. This topic is further explored in this issue's "Terry O'Shea on the Function, Fashion, and Future of Wearables," an interview with O'Shea, a Fellow of Hewlett Packard's Printing and Personal Systems Division.

Wearable products receive all the technological scrutiny applied to other mobile devices, but, in addition, we judge them as fashion items and social focus points. After all, we wear these devices on our bodies—it's hard to get any closer to people than that—and humans have a huge range of personal tastes and opinions. Some will only wear a device if it looks like jewelry, others enjoy a geek-chic approach, and yet others dislike wearing any of these devices at all. Likewise, there is little agreement on what is comfortable to wear, and an individual's comfort level with a

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Figure 1. The evolution of one kind of information device from pocket to wearable: (a) a pocket watch, (b) a Lancet trench watch from 1915 to 1917 with a shrapnel guard (photo courtesy of goldsmithwatchworks.com); (c) a current wristwatch.

device can change after prolonged use. We can further debate these points in the context of recent wearable products for animals,[1,2] since people also have strong opinions about what their pets wear!

Another human complication in wearable product design is deciding where we want to put what level of functionality. Critics claim that there's no motivation for a wearable device if a smartphone can provide the same service. Others regard the movement from phones to wearables in the same light as the migration from pocket watch to wristwatch during World War I (see Figure 1). Many argue in favor of a wearable tailored to do one thing only, whereas others believe a wearable must perform several functions to be worth justifying its place on our bodies.

Knowing Where to Wear It

Added to these basic design questions is another difficulty: it can even be hard to predict where people will wear their wearables. Certainly, people don't always place their devices in the "correct" location on their bodies, and a pair of glasses might find itself in many positions besides its intended perch on top of the nose.

As Kent Lyons and Halley Profita explain in "The Multiple Dispositions of On-Body and Wearable Devices," we should confront this problem head-on and consider the behavior and functionality of the device not just during its moment of use in an intended "disposition," but also during the other moments it's on a person, including the transitions between dispositions. This article provides guidance for designers to do exactly this, along with illustrative use cases. With this kind of user-centered design approach, we can create devices with increased functionality, wearability, and accommodation of resource requirements.

These different possible locations for wearables present both challenges and opportunities for sensing user activity and context, which can be critical to the wearable experience. Some information is more reliably sensed in certain positions on the body, but even fine-grained variations in position and orientation can make a difference. In "Sensor Placement Variations in Wearable Activity Recognition," Kai Kunze and Paul Lukowicz recognize this challenge and provide both a systematic description of positional variations in sensing as well as a set of methods to help engineers manage and mitigate them. For example, variations in position might reduce the accuracy of activity sensing via an accelerometer, and using training datasets across these different positions requires sufficient similarity between the different sets of signals. On the other hand, significant variations in data can allow us to determine where the device is on the body and correspondingly compensate for differences in the data.

Harvesting Energy

Another fundamental problem for wearables is battery lifetime. Users are generally unhappy about frequent recharging requirements, and from a compliance viewpoint, removing the device for recharging presents a risk that the user won't put it back on. Larger batteries aren't usually a welcome solution, because inherent to wearable design is the need to keep the devices small, rugged, and lightweight. For this reason, researchers have begun investigating energy harvesting to provide a sustained portable power source for wearable devices.

In "Human Motion: Sustainable Power for Wearable Electronics," Longhan Xie and Mingjing Cai evaluate two harvesters of kinetic energy from human body motion. They harvest human trunk motions from walking via a mass-spring-damping oscillating system in a backpack. To work efficiently with different backpack loads, they can adjust the stiffness of the oscillating system. They also harvest energy from

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human footstep motions using springs and sliders in a specially designed insole. Both of these approaches provide sufficient power to run a variety of practical on-body electronics.

Human motion offers some advantages for harvesting over other sources, because it doesn't require any surrounding infrastructure, and it can be available for harvesting indoors or out, night or day, unlike solar sources. Challenges include extracting enough energy from a harvester that's not too heavy or awkward for people to wear.

Interacting with Wearables

A final human-centric problem is how we interact with wearables. While wearables enable putting information exactly where we need it at a glance, and gathering input from sensors placed optimally on our bodies, they can also be harder to accommodate due to our social context and requirements to keep them small and lightweight. Regarding device output, it's important to us that what we wear behaves well and doesn't light up or make noises at inappropriate times or in inappropriate places. It goes where we go, and its behavior reflects upon our perceived behavior. Input is also context-sensitive, and there are times and places where using our voices or pulling out our phones to provide input isn't appropriate. In these contexts, easy text entry on the wearable itself remains a desirable goal for interacting with messaging, email, and calendaring applications.

In "Text Input on a Smart Watch," Andreas Komninos and Mark Dunlop motivate and evaluate one technique for enabling text input on small touch-sensitive displays. They focus on keyboard layout and attempt to reduce the burden on users by segmenting the display into seven rather large areas to avoid erroneous taps on the wrong "keys." The results of their user study suggest this mechanism is best targeted at short input tasks, but there are recognized paths to improvement, and the technique might be extensible to text entry on other surfaces, such as fabric or a user's own skin.

Regardless of current attention in the marketplace, or whether a particular smartwatch is more useful than another, wearables have been with us for a long time and are here to stay. Their capabilities and our expectations change with time, but basic problems remain. This issue of *IEEE Pervasive Computing* touches on designing for unpredictable human behavior, positioning sensors, powering wearables without removing the device from the body, and providing text input on very small displays. Yet this is only a modest subset of the intriguing problems wearables bring to the foreground. Thad Starner adds networking and heat dissipation to the list in this issue's Wearable Computing department, "How Wearables Worked their Way into the Mainstream."

If we move to implantables, disposable wearables, ingestibles, and smart prosthetic devices, the landscape becomes rockier. An alert reader will notice that even the experts (in this case, O'Shea and Starner) don't agree on what exactly constitutes a wearable. Ultimately, the goal might be the "unwearables" suggested by O'Shea—replicating the benefits of all these devices without the need to attach anything to the human body. P

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