

The Hardware Is Not a Given

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Commodity hardware enables a range of cost-effective ubiquitous computing research, but innovative custom hardware can drive compelling new user experiences.

One of the dreams of ubiquitous computing is an ecology of heterogeneous computer systems, built into the environment around us and acting in concert to make our lives easier and more fun. Fundamental to this vision is a movement away from the desktop computing metaphor, in which a single user interacts very intentionally via a display, keyboard, and mouse. Instead, many researchers imagine computers with very dif-

ferent forms that support rich and varied means of interaction.

In many ways, we're still a long way from achieving ubiquitous computing (A. Schmidt, "Ubiquitous Computing: Are We There Yet?" *Computer*, Feb. 2010, pp. 95-97). Nonetheless, during the past few years, computing devices have come to increasingly leverage characteristics associated with ubiquitous computing such as mobility, real-time connectivity, and sensing. Examples include satellite navigation, computer gaming, digital

photography, and, most prevalent of all, an array of mobile communication devices and services. As these new application areas become established, the limitations of traditional computer hardware are apparent. It's clear that a diverse set of technologies, form factors, and interaction techniques is becoming appropriate.

The community of researchers and developers who are exploring new directions for future generations of nondesktop computing systems has a difficult challenge—to build compelling new applications that make lives easier and more enjoyable as well as consider new technologies, form factors, and interaction techniques. Innovative software running on traditional computer hardware isn't always enough; there's a lot of value in pushing the boundaries all the way up and down the stack: from hardware, through software, and ultimately to the user experience.

TWO EXAMPLES

Movement-based game consoles such as the Nintendo Wii, with its motion-sensitive controller, and the recently announced Xbox 360 Kinect, which tracks body motion without a controller at all, are good examples of how changes in the hardware and form factor can be coupled with innovative software to deliver a revo-



Figure 1. The motion-based controller has created new markets for computer game consoles with the old and young alike.

lutionary user experience. In both cases, the designers combined fundamentally different electronic sensing technologies, such as motion sensors and vision systems, with novel software techniques ranging from signal processing to computer graphics. These technologies are creating new markets for computer game consoles, as Figure 1 shows.

Another example of how relatively small hardware changes can affect an entire market is evident in cellular telephony. Just a few years ago, there were essentially two established form factors for mobile phones: the clam shell and the candy bar. However, advances in multitouch sensing enabled this technology to migrate to mobile phones. The richer interaction afforded by multitouch input largely removed the need for physical keys, allowing the display to cover the device's entire front surface—thus a new form factor was born. With the inclusion of simple sensing technologies such as an accelerometer, the smartphone enables a range of compelling new user experiences.

BEYOND SMARTPHONES

The research community is naturally drawn to commodity hardware such as the smartphone and motion-sensitive game controller. These devices have enabled many new types of applications without any requirement to develop new hardware. Not only do they offer great value, but in many cases they readily support interoperability that can be leveraged to scale up research efforts. Smartphones in particular provide a standardized platform on which to develop, making it easier to run large-scale deployments of probes and prototypes. This in turn generates deeper insights than would have been possible with custom-built hardware.

But commodity hardware isn't a silver bullet. If we simply build new applications on existing hardware, we will often limit ourselves to evolutionary progress, missing the opportunity



Figure 2. The SenseCam wearable camera has a wide-angle lens and takes photos automatically, creating a visual diary of the wearer's day.

to create something revolutionary. Developing custom hardware requires considerable expertise, time, and money, but the flexibility it affords makes it worthwhile. Put simply, there are a great many things that you can't do with a smartphone.

SenseCam

SenseCam, shown in Figure 2, is a small, wearable camera with a wide-angle lens that takes digital still images automatically (S. Hodges et al., "SenseCam: A Retrospective Memory Aid," *UbiComp 2006: Ubiquitous Computing*, LNCS 4206, Springer, 2006, pp. 177-193). The camera doesn't have a viewfinder or display—it simply captures photos of whatever the wearer is looking at whenever triggered by its internal timer, motion, light-level, or temperature sensors. SenseCam is designed for very-low-power operation so it can run continuously all day, resulting in a visual record that is created without any intervention or conscious attention from the wearer.

In many ways the SenseCam hardware is very straightforward. Indeed, at first blush it would appear that a smartphone could readily be repurposed as a SenseCam. However, the particular combination of ease of use, wearability, robustness, thin form factor, wide-angle field of view, and lengthy battery lifetime offered by our custom-built research proto-

type is essential to its usability. For memory-impaired patients who have found the device invaluable, a smartphone-based implementation simply wouldn't deliver an acceptable user experience.

WISP

There are many other examples of the importance of bespoke hardware under the broad umbrella of ubiquitous computing. Intel Labs' Wireless Identification and Sensing Platform (J.R. Smith et al., "A Wirelessly-Powered Platform for Sensing and Computation," *UbiComp 2006: Ubiquitous Computing*, LNCS 4206, Springer, 2006, pp. 495-506) is essentially a special type of radio-frequency identification tag that contains a general-purpose microcontroller in place of the inflexible hard-coded integrated circuit used in commercial RFID tags. The WISP's ability to harvest power from a nearby RFID reader enables a new class of battery-less sensing applications very different from anything that could be performed with commodity hardware, let alone a smartphone.

Peppermill

Another example of power-harvesting research enabled through new hardware is the recent Peppermill project (N. Villar and S. Hodges, "The Peppermill: An Interaction-



Figure 3. The Peppermill is an interaction-powered user interface device that can be used to control a TV. Rotating the Peppermill clockwise with the red button pressed turns up the volume, and with the green button pressed increments the channel.

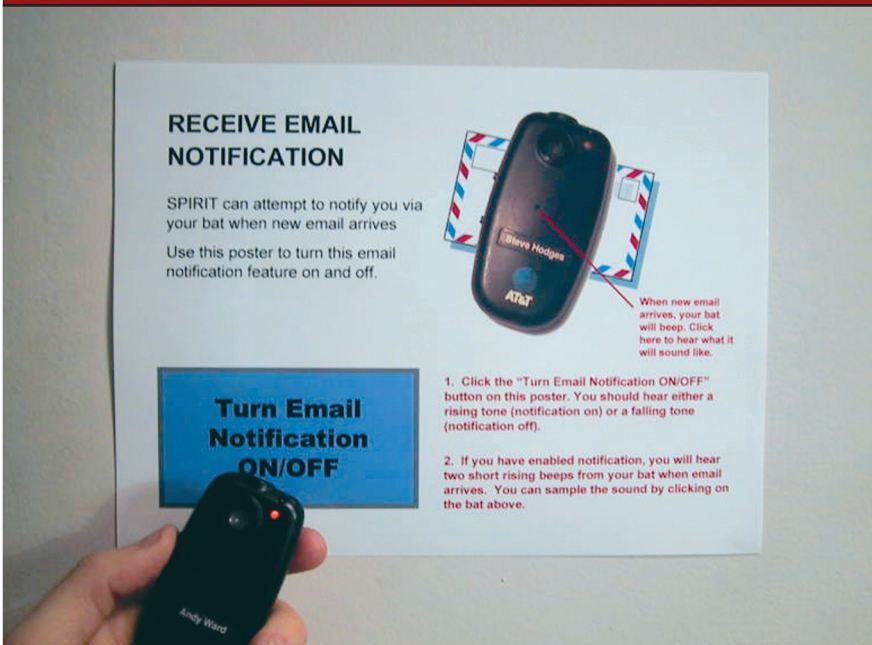


Figure 4. The Active Bat system enabled the prototyping and deployment of various location-based applications.

Powered User Interface Device,” *Proc. 4th Int’l Conf. Tangible, Embedded, and Embodied Interaction*, ACM Press, 2010; <http://tei-conf.org/10/uploads/Program/p29.pdf>). The simple and ubiquitous TV remote control inspired the project, which couples a novel interaction metaphor with a new device form factor. As Figure 3 shows, the user “grinds” the peppermill-shaped device to select the TV

volume and channel, simultaneously generating all the energy required to power the device.

ALTERNATIVES TO CUSTOM HARDWARE

Ubiquitous computing researchers face a dilemma: exploring new hardware designs and configurations is clearly valuable, but it can also be expensive. However, it isn’t neces-

sary to develop new hardware from scratch for every project. Sometimes a useful approach is simply to imagine what would be possible if different sensing systems and hardware form factors were available and reinforce this thought process by building Wizard-of-Oz prototypes.

For example, researchers can use infrastructure-heavy indoor location-sensing systems to explore applications that respond to the varying absolute and relative positions of multiple users and mobile devices. The Active Bat system (M. Addlesee et al., “Implementing a Sentient Computing System,” *Computer*, Aug. 2001, pp. 50-56) enabled numerous location-based applications like that shown in Figure 4 to be prototyped and deployed in a lab environment. Similarly, optical motion-capture systems such as that produced by Vicon (<http://vicon.com>) let research labs create an environment for evaluating new applications and interaction techniques.

Another alternative to developing custom hardware is to use someone else’s. Microsoft Research loaned out several hundred SenseCam prototypes to life-sciences clinicians and researchers, and more than 40 labs worldwide now use the device to study its effects on normal memory and on people with memory impairment. The images turn out to be a powerful memory aid; reviewing photos captured by SenseCam frequently elicits powerful recall, rekindling the thoughts and feelings the wearer experienced at the time. The results have been so successful that the device is now available commercially to support global research (<http://viconrevue.com>).

Intel has likewise made the WISP platform available to numerous researchers to explore various applications and new forms of interaction that aren’t possible using standard hardware. And Microsoft Research has made the power harvesting and direction-and-speed-detection

circuitry used in the Peppermill available as a separate Peppermill power board, shown in Figure 5. The complete design information is now available online (<http://research.microsoft.com/peppermill>) for anyone to experiment with and adapt to their own application ideas.

Easy-to-use and well-documented platforms like Arduino (<http://arduino.cc>) are making it increasingly straightforward for researchers and developers with little electronics development experience to prototype custom devices. The required building blocks, which include a variety of modules, sensors, actuators, and discrete electronic components are available ex-stock from outlets such as SparkFun (<http://sparkfun.com>).

Websites like MAKE (<http://makezine.com>) and Instructables (<http://instructables.com>) have created growing communities that generate valuable resources for ubiquitous computing researchers in the form of detailed instructions, code samples, and sample schematics for an incredibly diverse set of creative projects. In many cases, these materials can be readily adapted and extended to enable research beyond what is possible using commodity hardware.

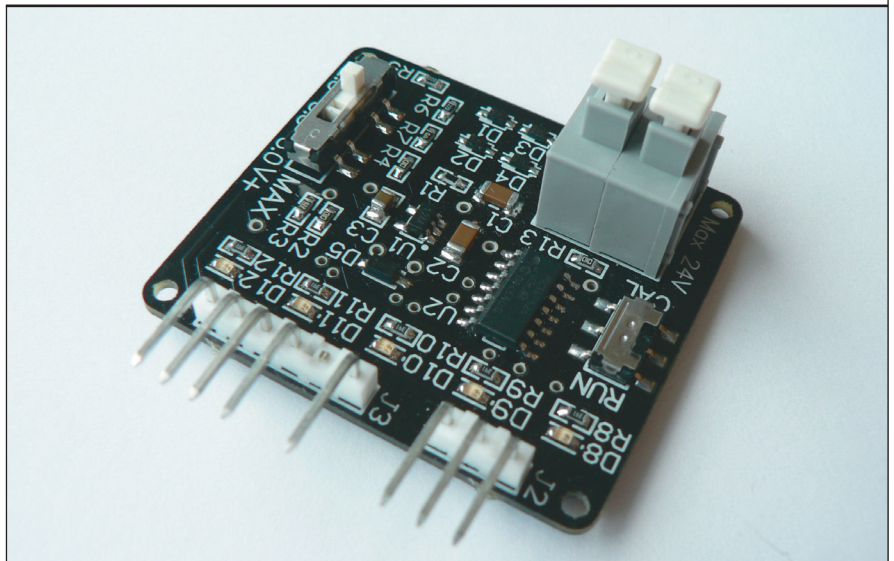


Figure 5. Peppermill power board. Microsoft Research has distributed more than 100 of these to the research and hobbyist communities to encourage exploration.

With so many resources available to the research and development community, there are growing opportunities to advance toward the ubiquitous computing vision. It isn't clear exactly where ubiquitous computing is going to take us, but one thing is certain: the hardware is not a given. **■**

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