Wearable Computing

Editor: Thad E. Starner ■ Georgia Institute of Technology ■ thad@cc.gatech.edu

Powerful Change Part 1: Batteries and Possible Alternatives for the Mobile Market

Thad E. Starner

Mobile phone companies sell more batteries than phones to consumers. The devices users buy generally include rechargeable batteries so that they are immediately useful. On average, however, the consumer must own more than one battery during the phone's life. The same is probably true for laptops and camcorders. Companies try to protect their batteries with various design and utility patents to keep third-party vendors from competing too heavily with their after-market sales. This protection is necessary because battery technology changes slowly—consumers receive little incentive to upgrade their batteries unless they fail or the consumer desires a larger one. Additionally, battery cost is tied to raw material costs, more than silicon chip or software costs, making batteries more similar to traditional trade goods than to the high-profit centers with which high-tech companies are familiar.

Power is a difficult issue and is often overlooked in mobile computers. However, innovative opportunities abound for exploring this problem. In this installment, we introduce the issue and propose some alternatives to batteries. In subsequent issues we'll address methods of being more power efficient by using resources both on the body and in the environment.

POWER PLAY

Battery energy is one of the most laggard trends in mobile computing.[1] Figure 1 shows the progression of technology in the last decade for laptop computers, which are now mostly mature. Generally, the laptop technology that the graph represents could be used—if repackaged in a body-worn device—while standing on a street corner in a major US city.

The graph depicts increases in performance as multiples of the state of the technology from 1990. Owing to the improvements' exponential nature, the *y*-axis is on a logarithmic scale. A high-end machine from 1990 (the base value of 1 in the graph) would be a 16-MHz 80386 with 8 Mbytes of RAM and 40 Mbytes of hard-drive space. The figure compares processor performance in terms of Intel's iCOMP index (www.cpuscorecard.com), RAM and disk storage on the basis of size, and wireless networks on the basis of maximum bits per second of data transfer. I determined the battery energy density on the basis of the technology type (nickel cadmium, nickel metal hydride, or lithium ion) and the progression these technologies made in increasing the joules stored per kilogram. I determined the graph's statistics by examining the typical specifications of the highest-end laptop advertisements in the December issues of *Byte* and *PC Computing* magazines for each year. The graph's wireless transfer speed line tracks the commercial, license-free, citywide networks available in the US (cellular standards, not 802.11 hotspots).

Although disk storage density has increased over 1,200 times since 1990, the lowly battery's energy density has increased by a factor of only three. Even the long-awaited advent of fuel cells will improve current technology by a factor of only about two. The lesson to mobile-device designers is clear: specify the battery first, then design the mobile device's electronics around it. Battery technology is the least likely to change in the 12-month development cycle and could be the most limiting factor in the design with respect to size, weight, and cost.

Wireless connectivity is also a conundrum for mobile designers. Although designers can control the CPU, RAM, disk, and battery in their devices, another party often provides wireless

UPCOMING EVENTS

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connectivity. The wireless connection might or might not be available at any given moment, so the device designer must either cache information for the user or refuse service. So, many devices, such as wireless PDAs, have nonvolatile RAM or disks so that the user can work offline. Using mass storage strategically can save battery power significantly because receiving and transmitting data from cellular and 802.11 networks requires substantial power.

In practice, the power for transmitting is proportional to the distance to the fourth power. Given exponential trends in disk density, we might soon be able to save power by caching a good fraction of static Internet content for a mobile Web surfer instead of connecting over power-hungry and expensive wireless networks (see the sidebar). Imagine a system that examines the user's email, Web history, and downloads and, on the basis of this data, continuously updates the user's mobile cache while the device has wired (or low-power) connectivity.

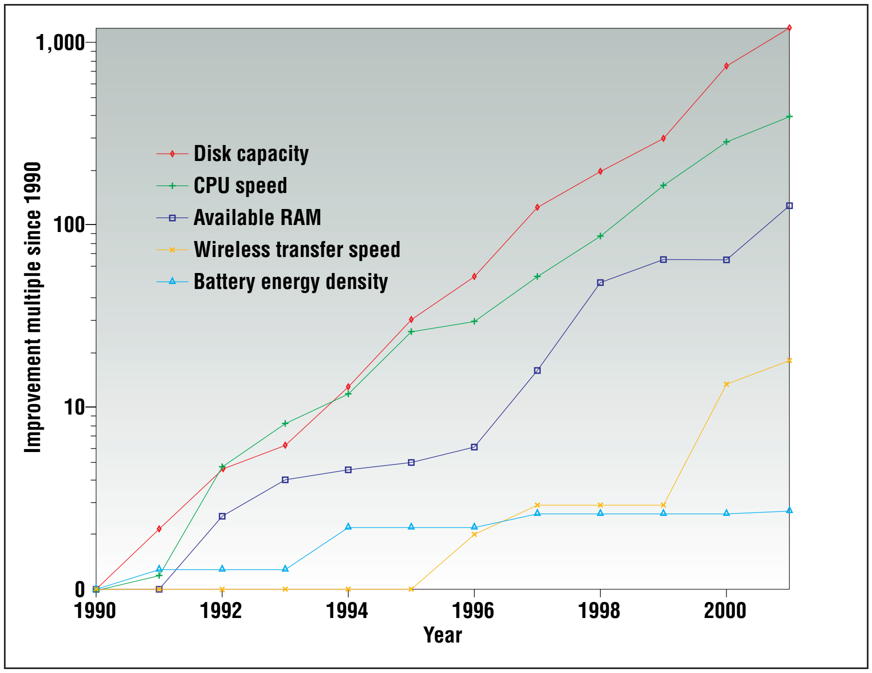

Figure 1. Improvements in laptop technology from 1990–2001.

POWER FROM THE PEOPLE

Can we get around the battery law—that is, owing to the physics involved, batteries will fall behind other mobile technology trends? Possibly. Wristwatches, in some senses the precursors to wearable computers, addressed this problem many years ago with the advent of the self-winding watch. Taking apart one of these watches reveals a 2-gram mass mounted off-center on a spindle. As the user moves during the day, the mass rotates on the spindle and winds the mechanism. A simple variant could use the same off-center mass design, but the mass would be a magnet. As the magnet spins past coils of wire mounted in the watch's sides, it induces an electrical current that can run low-power electronics.

At the 2003 International Symposium on Wearable Computing, Thomas von Büren and his colleagues theorized a similar approach using a spring-mounted, 1-gram mass.[2] Their experiments showed that the mass's vibrations can generate up to 200 microwatts of power while the user walks. If realized, such power recovery would allow for small, wireless, self-powered sensors that could be distributed on the body. Simply reporting the amount of the mass's vibration could act as a crude accelerometer.

Applications could include systems that monitor Parkinsonian tremors for better diagnosis and adjustment of medical dosage, gesture recognition systems, sports devices such as pedometers, and devices that monitor daily living activities for older adults with Alzheimer's or with a high risk of stroke or heart disease.

Finger power might provide a way to create wireless keyboards and mice without batteries. Self-powered buttons are not a new idea. Zenith televisions in the 1950s featured a self-powered remote control where a button, when pressed, would strike a tuned aluminum rod that resonated at an ultrasonic frequency. The TV decoded this sound pulse and changed channels appropriately. Joseph Paradiso and Mark Feldmeier created a similar system using a piezoelectric element that, when struck by a button, generates enough power to run a digital encoder and a radio that can transmit up to 50 feet.[3] Enocean is marketing similar technology (www.enocean.com).

Imagine a portable keyboard, such as the Twiddler (www.handykey.com), communicating wirelessly to the user's wearable in such a manner. In much the same way, you can imagine a small finger- or wrist-mounted trackball being self-powered. Moving the trackball would turn wheel encoders inside the device, both registering the movement and powering the device.

Another approach is to recover power from the environment by scavenging light or radio energy. Many calculators already use solar cells for this purpose, and some infrared location beacon systems have exploited the idea in the past.[4] Unfortunately, solar cells' brittleness and the amount of surface area they require makes their placement on the body difficult for any size greater than what can generate power in the submilliwatt range. However, you can imagine wearable computer accessories such as a parasol made of solar cells—

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graduate students could walk around in Atlanta's sun and have sufficient power to do their work! Well, perhaps not.

Another consumer item that might help reduce our battery dependence is the wind-up radios that BayGen and Radio Shack sell. The user can wind up the radio and have it store enough power for up to an hour of play. Carnegie Mellon University made a similar device for their 1W StrongArm-based wearable computer, the Metronaut.

STORE OR FORWARD?

The rapid density increase in flash memory drives makes the alternative of caching large amounts of information particularly interesting. Little or no power is required to maintain their state after writing.

Suppose that we can store information on a cellular phone in the form of a flash disk or send a wireless request for the information to the network. Reading a bit from modern flash memory requires approximately 10 picojoules or 1×10^{-11} joules per bit (see www.micron.com/products/flash/lowpower/flashcalc.html). However, transmitting a single bit at 0.6 W from a mobile phone at an aggressive 1-Mbps rate would require 6×10^{-7} J. So, for every bit transmitted in the wireless request for information, the same amount of energy could read 60,000 bits from a flash drive. This calculation ignores the radio's inefficiencies, the overhead generally associated with transmission error checking, and the amount of power necessary for receiving, processing, and storing the network response, which could be quite significant.

PEDAL POWER

A similar human-powered electronics idea was common in the 1940s with shortwave radios taken into the Australian outback. Soldiers and adventurers needed a way to communicate with the rest of the world without support from an electrical grid. Companies began making miniature bicycle pedal arrangements, similar to those sold in today's gadget magazines for under-the-office-desk exercising, to generate power for users' shortwave two-way radios.

An obvious extension for wearable devices would be to design a power recovery system for walking. In 1971, R. McLeish and J. Marsh tested a hydraulic pump system in the heel of a user's shoe for powering the user's bionic arm.[5] Although in the study the system generated sufficient power for everyday life, the hydraulic line from the heel to the arm must have chafed.

More modern systems have less ambitious power goals but look to power devices contained in the shoe. John Kymissis and his colleagues developed piezoelectric systems in the shoe that powered a microcontroller and radio that acted as an active identification badge for the user.[6] Roy Kornbluh at SRI developed a piezo polymer shoe system that could generate power in the watt range.[7] Given such advancements, you can imagine many different sensors and communication devices that might be embedded into a shoe heel.

In this issue, we presented some ideas on how to use human and ambient power to reduce a wearable's reliance on batteries. In the next issue, we'll examine techniques to be more efficient with power usage in general.

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