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How Green Is Green?

Roy Want

In a world that has become acutely aware of the environmental impact of energy consumption resulting in global warming, and the increasing financial burden of oil after the price spiked this past July to US$145 per barrel, energy conservation has become a hot topic. This is an opportunity for pervasive computing to play an important role in conserving our planetary resources and moving us toward environmental sustainability. Pervasive computing's primary green contribution is its ability to turn dumb technologies into smart power-aware technologies. By adding computing in combination with sensing and actuation, we can make systems automatically respond and adapt to their environment. Context-aware computing has long been applied to mobile systems, and has clear application in the design of smart power-aware systems that can respond to users' needs. In practice, adding a modest amount of embedded computation to a system, such as a home's heating, ventilation, and air conditioning system, can optimize the use of energy and still achieve the intended goal.

However, the addition of embedded computation and control systems isn't necessarily a free energy lunch. The question then becomes, "How much energy did it really take to manufacture the complex components to help us conserve?" Although the operation of these technologies might save energy, when considering the big picture, which includes manufacturing and transportation costs, the net saving might not be positive unless their operational life is sustained beyond the energy break-even point. Most consumer devices are made from a variety of materials including plastics, metals, glass, wood, and electronic components such as capacitors, resistors, and semiconductors. When you consider that these materials require manufacturing processes that are nontrivial in themselves, an interesting picture arises. For example, metals typically start life as an ore, which means it has to be dug or blasted out of solid rock, smelted in hot ovens, and then refined. If a high purity or an alloy is required, then further refinement using an energy hungry oven is needed. Semiconductor components are manufactured using an even more complex process requiring fabrication plants that purify silicon (originally starting its life as SiO_2, or sand), grow a single crystal ingot (another oven), slice it up into wafers with an electric precision diamond saw, and then implant, deposit, and etch other materials on its surface.

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Furthermore, these resources are likely found in very different locations, and require transportation to the manufacturing site. The transportation process will then continue as the base materials are combined into more complex composite materials or components, and then assembled into the final target product; most likely, at an automated production line that also requires electricity. Once complete, the product needs to be packaged, boxed, and transported by air, train, ship, or truck to the store. The entire chain of energy consumption, with the goal of providing a product to help us use energy more efficiently, is quite mind-boggling.

Although the total energy cost of manufacturing and transportation is offset by volume production, it still begs the question, "Was the savings goal achieved?" Having carried out a modest amount of research, I was surprised to find very little information on the total energy footprint consumed

Published by the IEEE CS ■ 1536-1268/09/$25.00 © 2009 IEEE

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during the end-to-end manufacturing processes of everyday electronic items. Perhaps some knowledgeable readers have access to more detailed research on this matter?

Another measure of green-ness uses global warming as the central issue, and measures environmental impact in terms of carbon footprint. In other words, the amount of atmospheric CO_2, a major contributor to global warming, that is created in the manufacturing of the items we use. All the extraction, refining, assembly, and transportation of materials will typically consume fossil fuels and add to the carbon footprint. However, this doesn't take into account other types of environmental impacts, such as pollution, or the efficiency of the process using the resources involved. For example, a classic question we might pose is whether washing the family dishes in a dishwasher each evening is more, or less, green than using paper plates and throwing them away afterwards. At first consideration, using paper plates seems extravagant and uses up valuable trees. However, growing trees take CO_2 out of the atmosphere, makes it work for us in the form of paper plates, and then slowly returns it to the atmosphere as the plates decay in our landfills. Although the dishwasher allows for the efficient reuse of ceramic dishes day after day, it uses electricity—to heat water, wash, and dry the items—which is likely generated from fossil fuel; this process also uses water, which in some areas is a scare resource. Finally, ceramic plates had to be made from clays that were oven-baked and then glazed for many hours in an energy-consuming kiln, and have a larger energy footprint than a paper plate. Furthermore, a ceramic plate can break, or its pattern can go out of style. The conservation answer isn't always easy or straightforward.

Considering more on the question of "How green is green?" let's examine two culturally popular energy-conserving solutions that address the issue of environmentally sustainability: *green homes* and *hybrid cars*, both of which are relevant to the application of pervasive computing.

A green home is an all-encompassing term that includes the concept of *smart home*, but also includes the careful design and planning around the materials used to build the structure, ensuring appropriate insulation, and taking orientation, sun exposure, thermal absorption, and radiation into account. The term smart home also refers to environmental sensing and automatic control of lighting, forced-air heating, air-conditioning, and water heating to best meet the occupants' day-to-day requirements. Studies show that these systems can optimize the use of energy above and beyond what could be done manually (if we remember to!). However, the cost of manufacturing smart components is a potential issue when you consider the number of devices needed for a typical deployment. For example, every light switch, power outlet, water heater, furnace, and air conditioning unit needs to be instrumented. If motion sensors are required to sense people in certain areas, you will need to install additional motion sensors.

I have some personal experience automating my home with X10 compliant power-line control systems. The

IEEE Pervasive Computing (ISSN 1536-1268) is published quarterly by the IEEE Computer Society. IEEE Headquarters, Three Park Ave., 17th Floor, New York, NY 10016-5997; IEEE Computer Society Publications Office, 10662 Los Vaqueros Circle, Los Alamitos, CA 90720-1314, phone +1 714 821 8380; IEEE Computer Society Headquarters, 2001 L St., Ste. 700, Washington, DC 20036. Subscription rates: IEEE Computer Society members get the lowest rates and choice of media option – US$44 (print and online access). Go to www.computer.org/subscribe to order and for more information on other subscription prices. Nonmember rate: available on request. Back issues: $20 for members and $169 for nonmembers.

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FROM THE EDITOR IN CHIEF

first issue is that the devices are quite expensive and therefore offset the benefits owners will see on their gas and electric bills. The second is that the components replacing simple switches are considerably more complicated and subject to failure. After a couple of years, I found at least two of my dimmable X10 light switches had failed, and one became intermittent in a very frustrating way. It takes extra time and effort to maintain, debug, and replace these components as they age, something many of us wouldn't expect to do. After all, a conventional light switch typically doesn't fail, and if you aren't a do-it-yourself smart-home hobbyist, this means another maintenance bill to pay.

In California and other Sun Belt states, roof-mounted photo-voltaic solar cells are becoming popular. Modern systems have the ability to both use the power to supplement power as needed in the house, and send excess power back to the electric power grid where other consumers can use it, and effectively run the local meter backward. Pervasive computing is part of this solution. Embedded computation in the distribution panel can decide how to use the generated power, and in combination with electric Storage Heaters (http://en.wikipedia.org/wiki/Storage_heater) and battery-backup systems, can also optimize by trading off the cost of peak and off-peak electricity tariffs. This is a complex web of optimization that is best suited to a smart embedded controller.

The second popular green solution is the hybrid gasoline/electric car, of which the most successful design has been the Toyota Prius. In 2007, the US Environmental Protection Agency declared it the most fuel efficient vehicle in the US. It also sold more than 280,000 units worldwide in 2007, and claims 51 percent of the US hybrid market. The car runs on gasoline, or electricity stored in an internal 1310 Watt hour nickel-metal hydride battery. It's a classic example of the application of pervasive computing, with embedded computation enabling a trade-off between the gasoline and electric systems. Its internal Hybrid Synergy Drive (HSD) combines power from the gasoline engine and the electric motors to optimize the car's total energy consumption. For low-speed operation, it can run entirely on electricity where it's most efficient. When slowing down, energy is conserved through a regenerative breaking system, which converts the car's kinetic energy into an electric current that is used to recharge the batteries. Perhaps the most important aspect of the design is that the efficiency, and the source and direction of energy flow, is presented through an LCD screen. Users concerned about conservation can therefore adjust their driving behavior to ensure optimal operation. In terms of the true cost, comparing the manufacturer's suggested retail price of five representative hybrid cars from mainstream manufacturers with their nonhybrid equivalents, there is a $5,000 price difference on average. Assuming $4 per gallon and 10,000 miles driven per year, it would take an average of 11.4 years to break even (a fairly long life for a car), and this doesn't take into account the likely extra maintenance cost associated with more complex cars. Although energy conservation is clearly important for the planet, we have some way to go to make it financially advantageous to the individual.

It's clear that pervasive computing can still play an important role in optimizing the use of energy despite the hidden costs of applying it to conservation. Given that we're already manufacturing computing components for a wide spectrum of applications in the computing industry, the energy production costs for many of these items are already amortized over many products. Thus, in terms of energy, the manufacturing costs for many components have already been paid for, and this advantage can be realized when applied to the goal of promoting environmental sustainability.