Human Power for Portable Computing

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INTRODUCTION

The world has observed the accelerated change in the technology in the last decades. Computer processing speed, RAM memory, disk capacities, and wireless velocity are growing at a fast pace, as shown in Fig. 1 (updated from Starner and Paradiso, 2004, by Romero, 2010). This is evidenced by the use of portable or wearable computing, such as with the ubiquitous smartphones and tablets. Although batteries have evolved from disposable zinc-carbon and alkaline batteries to rechargeable cells using Ni-Cd to the lithium-ion cells, this technology has not evolved at the same rate as the electronics it now powers (see Fig. 1). Thus, users are limited to a moderate use of portable electronics for one battery charge, to frequent recharges for heavier use, or to use spare batteries for extended operation. The energy content depends heavily on the energy source, as shown in Table 1. At the same time, the shrinking electronics has allowed lower power consumption devices that enable more hours of operation. Still, devices need to be frequently connected to the grid for battery charging, or batteries need to be replaced with regularity. Table 2 summarizes the level of the power requirements of some electronic devices. The matching of the power availability from several sources (energy, from Table 1, divided by time) and power consumption (Table 2) generally decides the trade-off of a device's capacity and battery size.

In the last decade, there has been an increased motivation to do research on energy harvesting (harnessing energy from the environment) to power electronics. One of the objectives behind it is to extend battery life, or even replace it as the main energy source. Since the human body requires around 2000 dietary calories (8.4MJ in 24 hours, or the energy equivalent of a liter of gasoline), harnessing a small part of it seems a practical way to save in for battery dependence reduction.

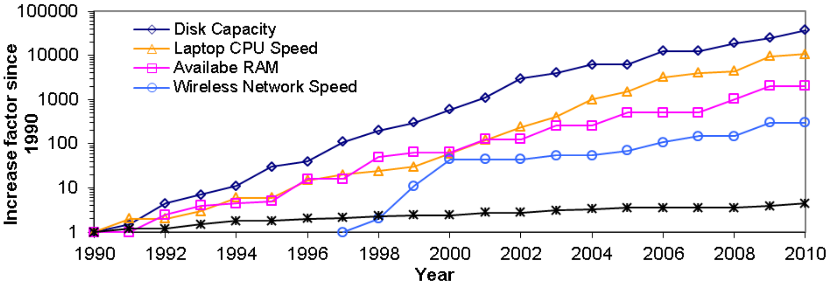

Figure 1: Technology trends since 1990

Table 1: Capacity of Energy Sources

Energy Source	Energy (J)
Button Cell Battery	~10^3
AA Battery/Cellphone Battery	~10^4
Laptop Battery	~10^5
Lead-Acid Battery	~10^6
Liter of Gasoline	~10^7
Average Human Diet	~10^7

Table 2: Electronic Power Consumption

Electronic Device	Power (W)
PC	~10^2
Laptop	~10
Portable Device (smartphone/tablet)	~1
MP3 Player	~10^{-1}
Smoke Alarm	~10^{-2}
Low Power Electronics	~10^{-3}

BACKGROUND

Energy generation from human activities has been focused on using mostly thermal energy, body motion, and more recently through the use of glucose fuel cells. Thermal energy generation has the advantage of requiring no moving parts, but the generation efficiency is theoretically limited to less than 5% (Starner, 1996). If a thermal generator could harvest the human body heat released to the environment (~300W), then up to 20W could be extracted, but such a device would require covering the entire body. A more practical approach would be reducing the thermal generation area (5% coverage would lead to a maximum of 1W of power). Thermal generators in wristwatches have been capable in producing 13-60μW/cm^2 (Flipsen, 2005; Paradiso and Starner, 2005), while up to 400μW/cm^2 (2mW of power) have been demonstrated using an added heat sink (Mateu et al., 2007).

Energy generation from motion (either actively or passively) has been more extensively investigated (Beeby et al., 2006; Romero et al., 2009). Active energy generation (through bicycle pedaling, hand cranking, shaking, etc.) shows that the human body is capable of producing power from 2W (hand crank generator) up to 600-800W for professionals athletes (cyclist and rowers) in short periods of time (Flipsen, 2005). Sustained hand cranking has also been studied, and it has determined that 14W of electrical power can be obtained continuously using one hand (Slob, 2000). Thus, devices requiring a relatively high power output should consider active energy generation as a strategy to enhance battery life.

PASSIVE ENERGY GENERATORS

Passive energy generation uses body motion such as the heel strike, the trunk up-and-down movement, or the arm swinging when walking. Generators based on this type of motion show promise for powering less power hungry devices (from mW to watts). Electromagnetic and piezoelectric technologies are the most common technologies used for electrical energy conversion. As expected, larger devices provide a higher power output.

An electromagnetic generator mounted on a custom-made knee brace that harnessed the swinging back of the leg (similar to regenerative braking) was capable of producing up to 4.8W of power. Another electromagnetic generator embedded in a vertically movable backpack structure produced up to 7.4W when transporting a 38kg load. A 3mm deformation by the shoe sole on an 80kg individual walking at 1Hz translates to 4W of mechanical power. This energy has been harvested through different techniques, producing power outputs from 1-8mW using piezoelectric shoe soles up to almost 700mW using an hydraulic and piezoelectric shoe platform (Romero et al., 2009). Piezoelectric knee implants have been shown capable of producing 0.85mW continuously while walking. Another tubular electromagnetic generator design carried inside a backpack showed a power generation up to 0.95mW while walking as well (Saha et al., 2008). The extraction of energy from walking and running has also being investigated with smaller geometries. Spherical geometries (under 4cm^3) have provided up to 1.4mW of power (Bowers and Arnold, 2008), while planar geometries (under 2cm^3) produced up to 0.5mW of power (Romero et al., 2011).

Another approach is the use of direct glucose fuel cells, or bio fuel cells, that use glucose rather than hydrogen as the fuel. The main advantage is that they can be implanted inside the body using blood glucose as the input energy source. Additionally, fuel cells only produce water as byproduct. A prototype was showed capable of producing up to 0.14mW of power (Nishizawa et al., 2005). Even urine-based designs have been presented. Such a design was able of producing up to 1.5mW (Lee, 2005). Although power outputs around 1mW are not capable of powering portable computing devices, they can be used as sensors for monitoring patient physiological responses or for some biomedical devices.

CONCLUSION

Portable electronics is an area where a tradeoff between functionality and battery life is on the hands of the equipment designers. This is something that can be observed nowadays with smartphones and tablets. Portable active generators are capable of producing enough energy for devices requiring more than 1W of power, while passive generators can extend operation of devices with smaller power requirements.

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