A System Design and Rapid Prototyping of Wearable Computers Course

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Abstract

This paper describes a custom design approach as applied to power management in an innovative course on rapid prototyping of computer systems at Carnegie Mellon. The paper identifies the major components of power consumption in a wearable computer, and evaluates their respective contributions to power consumption. We have quantified the power consumption of text-, graphics-, and speech-based interfaces, providing a guideline for the design of future wearable/mobile computer systems.

Goal

The interface design must be carefully matched with user tasks and balanced against energy consumption. Many complex and interrelated issues determine the balance between ease-of-use and power consumption.

Motivation

The effect of user interface on energy consumption can be evaluated by developing several different interfaces and measuring and comparing the ease-of-use and energy consumption.

Approach

The user interface and information representation selected for an application can lead to orders of magnitude difference in energy consumption.

Consider the interaction between usage and the design of the user interface. Various forms of user interfaces place varying requirements on the performance and capacity of the electronics. The number of operations to perform a user input or output can be related to energy consumption as:

Energy to do user task =
(number of functions to perform a user task)
x (millions of operations / function)
x (watts / million operations)
x (time of operation)

The type of data to be exchanged must also be selected. For example, consider filing a report consisting of the answers to 100 different questions each having a single word response selected from a menu. Four possible data representations are:

- Text. Assuming one word per question, an average of five characters per word and 8 bits per character, 4000 bits of information would be generated.
- Audio. Assume that the user files an audio report that requires 60 seconds to complete. Sample encoding for audio requires 2.4 Kbits per second.
- Still picture. Assume a VGA picture composed of 640x480 pixels with 16 levels of gray scale for black and white. The result is 1.23 million bits of data. A color picture with 8 bits for each primary color requires six times more data, or 7.38 million bits.
- Video. The report could also be filed with video clips. Assuming the VGA quality as the still picture at 30 frames per second, a 10-second video clip requires 300 times more data than the corresponding black and white or color picture. A video frame can be compressed by a factor of 30 on average and at the expense of eight million operations. The type of interface and type of data can have up to four orders of magnitude difference in energy consumed, as shown in Table 1.

Experiments and Results

The energy consumption of three interface modalities in a database query application were measured and analyzed. The energy consumed by different interfaces is affected by two factors: task time and task current. Our results, shown in Figure 3, indicate that the task execution time of text and graphic interfaces is similar, but due to higher base current and application current, the total energy consumed by the text interface is 21.3% less than consumed by the graphics interface. Graphics and speech modalities draw similar currents. However, it takes three times longer to complete the task using speech; therefore it consumes more energy overall. To perform the same task, the lowest and highest total energy consumed varies by a factor of four among the three interface modalities.

Conclusions

We emphasize the importance of the system level approach to design of wearable computers, in particular, the choice of user interface modalities on their power consumption. Our results indicate that it is critical to consider both the time required for a user to complete a task using a given interface modality and the amount of power consumed by the use of that interface modality. We have quantified the power consumption of text-, graphics-, and speech-based interfaces, providing a guideline for the design of future wearable/mobile computer systems.

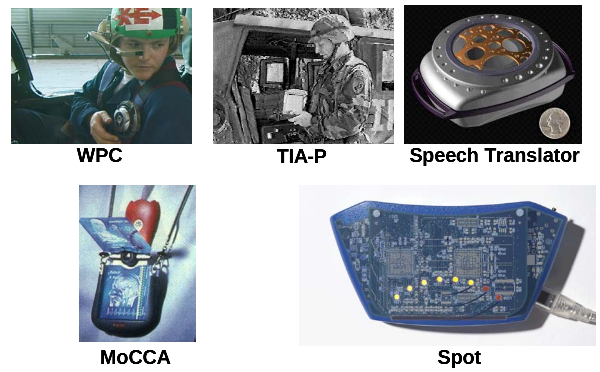

Figure 1. Representative examples of CMU wearable computers with extensive power management and optimization research

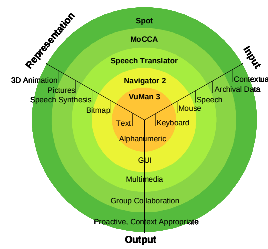

Figure 2. Wearable computer user interfaces and information representation

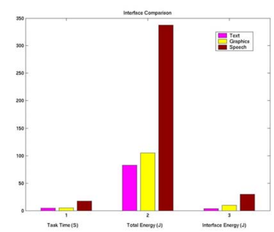

Figure 3. Task time and energy consumption for different interface modalities

Table 1. Impact of user interface on power consumption

Physical Interface	User Interface		Computing			Transmit		Total Energy (whr)	Battery Weight (kg)
	Type	Data Type	Inter face (mop)	Compre -ssion (mop)	Energy (whr)	Bits	Energy (whr)		
Mechanical	Textural (1MIPS)	100 Words Text	300		$8.3X10^{-4}$	$4X10^{3}$	$1.4X10^{-5}$	$8.5X10^{-4}$	$4.2X10^{-6}$
		60 sec sound	60		$1.7X10^{-4}$	$1.4X10^{5}$	$4.9X10^{-4}$	$6.6X10^{-4}$	$3.3X10^{-6}$
		B&W still	30		$8.3X10^{-5}$	$1.2X10^{6}$	$4.3X10^{-3}$	$4.4X10^{-3}$	$2.2X10^{-5}$
		10 sec color video	30		$8.3X10^{-5}$	$2.2X10^{9}$	7.53	7.53	$3.8X10^{-2}$
		10 sec color video	30	80	$6.8X10^{-3}$	$7.4X10^{7}$	0.251	0.258	$1.3X10^{-3}$
Audio	Speech Recogni -tion (150 MIPS)	100 Words Text	45000		0.125	$4X10^{3}$	$1.4X10^{-5}$	0.125	$6.3X10^{-4}$
		10 sec color video	4500	80	$1.9X10^{-2}$	$7.4X10^{7}$	0.251	0.27	$1.4X10^{-3}$

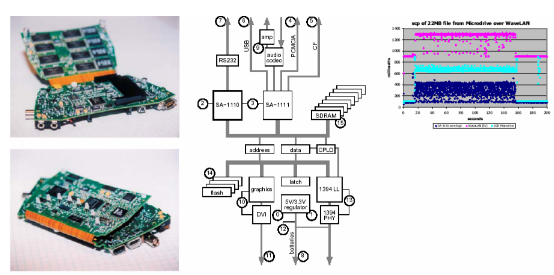

Figure 4. Spot Power Instrumentation

Table 2. System components and their techniques for mitigating energy issues

	Component	Mitigation technique	Improvement
Power consumers	Communication	Energy-aware network routing	Up to 50% fewer hops, 50% less energy
		Local processing	Delineation of local vs. remote based upon communication/processing cost
	Computation	Remote processing	
		Dynamic CPU speed-setting	Prediction of idle time and active power within 5% of actual
Power sources	Battery	Reduce peak draw	Up to 50% greater available energy