A System Design and Rapid Prototyping of Wearable Computers Course

Asim Smailagic, Daniel Siewiorek, Lu Luo
Institute for Complex Engineered Systems and School of Computer Science
Carnegie Mellon University
Pittsburgh, PA 15213
asim@cs.cmu.edu

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. We emphasize the importance of the choice of user interface modalities on power consumption of wearable computers. 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.

1. Introduction

Carnegie Mellon's innovative course, Rapid Prototyping of Computer Systems, has been creating a novel generation of wearable computers for an industry partner every semester over the last ten years. These generations of wearable computers have been field tested and used for real applications. In this paper, we emphasize the importance of the choice of user interface modalities on power consumption of wearable computers.

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. Simply trading off ease-of-use for lower per operation power consumption may result in higher task energy consumption due to the increase in the number of operations needed to traverse a less intuitive interface. 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.

For most generations of CMU wearable computers, we have performed extensive power management and optimization research, and Figure 1 shows just several of these examples [1,2]. It is convenient to use instrumentation

Proceedings of the 2003 IEEE International Conference on Microelectronic Systems Education (MSE'03)
0-7695-1973-3/03 $17.00 © 2003 IEEE

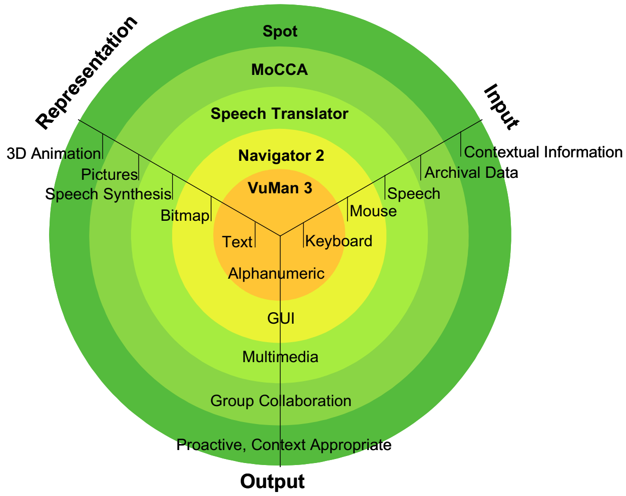

Figure 2. Wearable computer user interfaces and information representation

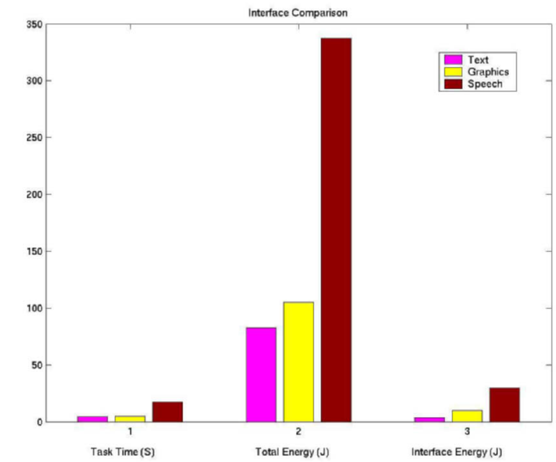

Figure 3. Task time and energy consumption for different interface modalities

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	$1.4X10^{-3}$

for power monitoring purposes and be able to generate real-time profiles of power consumption.

2. Approach

The user interface and information representation selected for an application can lead to orders of magnitude difference in energy consumption. A range of user interfaces for some of our representative wearable computers is shown in Figure 2.

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. The software designer can reduce the number of bits that need to be transmitted by applying compression algorithms. A video frame can be compressed by a factor of 30 on average and at the expense of eight million operations.

Consider the design of the input interface using variations of user interfaces and data representations for the task described above. Table 1 shows the energy required for the computation and communication portions and the battery weight (a metric which users can more directly relate to than Watt-hours) required to perform the task. As can be seen the type of user interface and the type of data selected can have a dramatic impact on the energy consumption and weight of the system. For example, a ten-second color video clip without compression would require 37.5 grams of battery weight. As shown in Table 1, the type of interface and type of data can have up to four orders of magnitude difference in energy consumed.

3. 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.

4. Conclusions

This paper emphasizes 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.

5. Acknowledgments

We would like to acknowledge funding support received from the National Science Foundation, DARPA, and the Pennsylvania Infrastructure Technology Alliance.

6. References

[1] Siewiorek, D., Smailagic, A., and Lee, J.., "An Interdisciplinary Concurrent Design Methodology as Applied to the Navigator Wearable Computer System," *Journal of Computer and Software Engineering.*, Vol. 2, No. 3, Nov 1994, pp. 259-294.

[2] Smailagic, A., Siewiorek, D., "Application Design for Wearable and Context Aware Computers," *IEEE Pervasive Computing,* Vol. 1, No. 4, 2002, pp. 20-29