Online Power Monitoring for Wearable Systems*

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Abstract

This paper describes a method for collecting real-time energy consumption statistics for a custom wearable system. We describe an implementation of hardware and software which provides detailed trace data for every major subsystem of a wearable computer, including the microprocessor, memory, and I/O. This design is entirely self-contained, requires no external instrumentation, and imposes low computational overhead. By using a comprehensive power monitoring scheme, wearable system designers can better understand the energy/performance tradeoffs implemented by applications, communications, and human interaction devices.

1. Introduction

Power is an important consideration for wearable system designers. The energy consumption profile of a wearable computer determines how long a system will run given a battery size, or conversely, how large a battery must be to achieve a specified uptime. Batteries may contribute significantly to the overall volume and mass of the wearable system. For this reason, wearable designers want to know exactly how energy is consumed in the system, so that an accurate battery specification can be made.

Previous work has examined the relationship between program structure and system energy consumption. Dynamic power measurement uses an external sensor to collect traces of system energy consumption over time [1, 2]. Process traces from the operating system are then used to determine the energy costs of applications. This method requires an offline correlation step, in which the energy and process traces are combined. By integrating online energy sensors with the wearable hardware, the operating system can treat energy as a managed resource. Further, energy-aware applications can adjust their behavior at run time to satisfy user energy and performance goals.

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2. Implementation

The Spot wearable computer, shown in Figure 1, includes a power monitoring feature which can provide online, high-resolution energy consumption data. Sensors on Spot measure energy consumption in sixteen separate subsystems, and report the results back to the microprocessor. The monitoring devices perform root-mean-square computations on the measured samples, thus reducing overhead at the host processor.

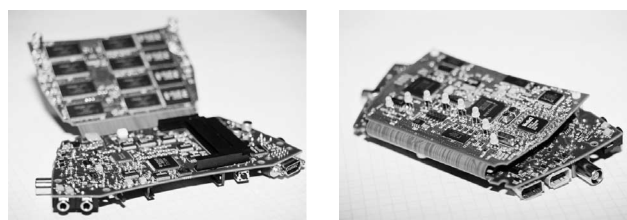

Figure 1. The Spot wearable computer.

The monitors are Crystal Semiconductor CS5460 Single Phase Bi-Directional Power/Energy ICs. Each of the eight devices has two monitoring channels, which we have configured for voltage monitoring operation. Precision inline resistors have been added to the power inputs of various components, and the monitors measure the potential drop across these resistors.

The CS5460 devices are all clocked in parallel using a 3.6864 MHz signal generated by the SA-1110 microprocessor. Communication between the host processor and the monitors occurs via a four-wire interface. A shared chip select, shared serial clock, and eight serial data input lines are connected to a latch on the processor static memory interface. Eight serial data output lines return information to the processor through a transparent latch, also on the static memory interface. This design permits all eight devices to be updated in parallel, ensuring that the power samples are in phase.

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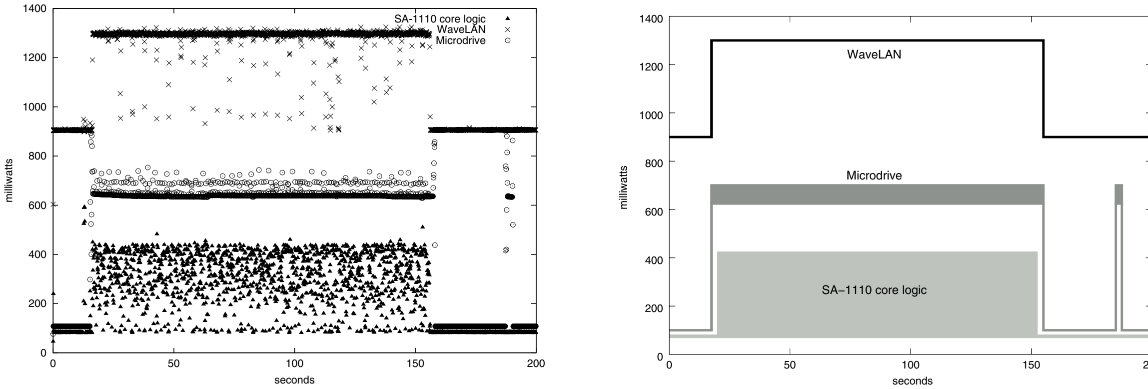

Figure 2. Power measurement of encrypted wireless transfer from disk.

An example of the data collected by this design is shown in Figure 2, where absolute power consumption for three subsystems is plotted. The trace shows a run of *scp*, in which data are read from a Microdrive, encrypted, and then transmitted using a 5V WaveLAN 802.11 radio. This information is interesting, as it shows that the active energy consumption of the radio is twice that of the rotating drive, and three times that of the microprocessor. Further, it shows that while *idle*, the radio draws nine times the power of either the drive or the processor.

The sixteen power monitoring points are shown in Figure 3, numbered by hardware channel identifier. In addition to instrumenting the processor and card slots, the Spot power monitors cover the flash memory and SDRAM, the audio amplifier, the graphics subsystem, and the FireWire subsystem. Several external ports on Spot supply power to peripherals; the monitors cover power rails for RS232, USB, and DVI devices. The main 5V and 3.3V switching regulator outputs are monitored, which give an aggregate measure of system power consumption before regulator efficiency losses. Finally, since Spot can be powered via FireWire or by hot-swappable modular batteries, two high-voltage monitoring points are located at the main power input; this permits software to determine which power source is actually in use.

The CS5460 devices are operated by a kernel device driver, which exports a general power monitoring interface to applications. A user program queries the driver for monitor channel descriptors, which include hardware-specific information such as sample range and sense resistor values. The program is responsible for knowing the common mode potential on each channel, which is adjustable in the case of the processor core supply, and dependent on external devices in the case of the FireWire and battery power inputs. The monitoring interface permits the program to specify per-channel offset and gain calibration parameters. The program may also specify the sampling period to be applied to all channels.

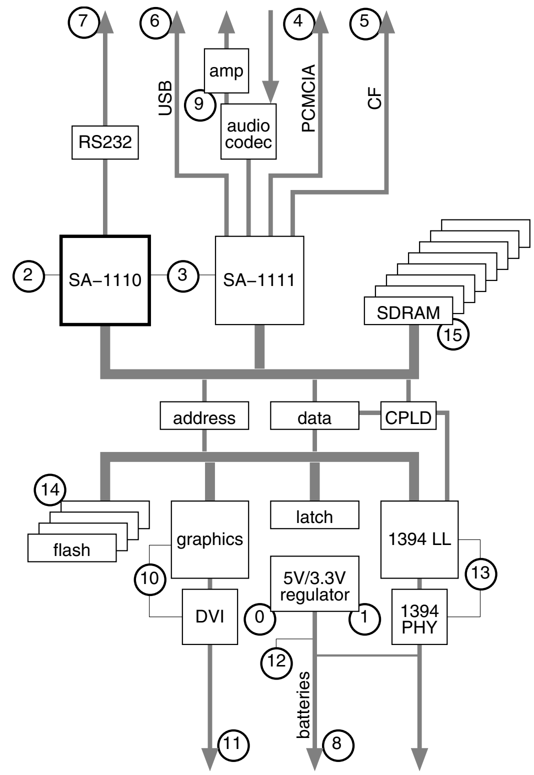

Figure 3. Spot power monitoring points.

References

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