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Integration of thermoelectrics and photovoltaics as auxiliary power sources in mobile computing applications

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Abstract

The inclusion of renewable technologies as auxiliary power sources in mobile computing platforms can lead to improved performance such as the extension of battery life. This paper presents sustainable power management characteristics and performance enhancement opportunities in mobile computing systems resulting from the integration of thermoelectric generators and photovoltaic units. Thermoelectric generators are employed for scavenging waste heat from processors or other significant components in the computer's chipset while the integration of photovoltaic units is demonstrated for generating power from environmental illumination. A scalable and flexible power architecture is also verified to effectively integrate these renewable energy sources. This paper confirms that battery life extension can be achieved through the appropriate integration of renewable sources such as thermoelectric and photovoltaic devices.

Keywords: Renewable sources; Thermoelectrics; Photovoltaics; Piezoelectrics; Sustainable power management; Battery life extension

1. Introduction

Sustainable power management issues such as the extension of battery life have been receiving increased attention for thin and light mobile computing platforms [1]. Extended battery life has potential impacts on both system performance, as exemplified by a lower maximum clock frequency, and on constraints regarding the attainable thermal envelope. In addition, ergonomic requirements such as a comfortable outer skin temperature, and low acoustic noise from the system fan have also become important considerations. To achieve this extended battery life, the critical development areas that have been identified in the industry include energy efficient cooling, higher density energy sources, fast renewable sources, and enhanced power and thermal management features [2]. Much work has been done on silicon power efficiency techniques, power management features, and new costly cooling technologies. An approach that has not been thoroughly investigated is to model each platform as an isolated island where access to the resources of the "mainland" entails high cost. This dictates the effective use of energy sources in the vicinity of the computer. An example of an energy source in the vicinity of this island is the 50 W (or more) system thermal power dissipated, which, in a size constrained system, has driven elegant cooling technologies [3] such as heat pipes.

A holistic approach is taken in this paper to identify the potential benefits derived from the integration of thermoelectric (TE), photovoltaic (PV) and piezoelectric modules in mobile computing platforms, to potentially extend battery life. The integration of these modules requires appropriate power electronic conversion techniques. To address the additional efficiency issues posed by the implementation of these power conversion approaches, an efficient conversion system was developed to convert low, intermittent voltage levels to an appropriate system dc-bus voltage, using a two level asynchronous Dixon charge pump [4]. Another challenge encountered with the integration of TE devices is the associated increased resistance to heat flow. The proposed solution involves the use of the TE module as a generator in periods of low intensity processor use, and as a cooling device during times of high intensity use [5,6]. This approach essentially allows the excess microprocessor and chipset cooling capabilities, beyond

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those needed by most workloads, to be used to extend the battery life.

This paper reviews previous work in the field and discusses the potential benefits derived from the integration of TE, PV and piezoelectric modules in mobile computing platforms. Sustainable power management issues are also discussed that drive mobile computing design specifications in order to address the fundamental challenges of generating supplemental power from low voltage auxiliary power sources. Analyses and experimental results are included using TE and PV modules, and implementation issues are discussed including the potential benefits derived from the use of state-of-the-art materials and devices in this premium application. Appropriate power architecture designs and control schemes are proposed and demonstrated to effectively and simultaneously employ TE and PV sources to provide supplemental onboard power generation.

2. Sustainable power management

To maximize the potential benefits of integrating renewable sources into mobile computing systems, the desirable system properties must be considered to drive the appropriate design decisions. Thus, it is important to briefly describe and analyze these system parameters.

2.1. Desirable properties of mobile computing

The current design trends in thin and light notebook systems can be summarized as

(i) Longer battery life: new technologies [1] drive energy efficient operation and longer lasting batteries.
(ii) Performance on demand: the performance is expected to scale up to desktop computing capabilities over time.
(iii) Compact design: systems become thinner, smaller, and lighter in order to enable mobility which makes it challenging to cool high power density components.
(iv) Cost: mainstream mobile computing platforms need to pay close attention to costs in order to enable large market penetration.

Clearly, the mainstream mobile computing platforms available in the market lie at the intersection of the above requirements. The "cost" requirement prevents expensive solutions from being deployed to address issues associated with (i)–(iii), though clearly when sufficiently significant gains are possible these solutions will be employed. For example, mobile computing applications have historically been early adopters of advanced battery technology, such as NiMH and Li-ion batteries, which has aided their widespread adoption in more mundane applications (e.g., shavers). Likewise, the adoption of heat pipes in processor cooling in current mobile computing platforms is an example of the adoption of a niche application to address the problem of how to achieve efficient cooling in a very thin platform. It is therefore possible that an option perceived as "expensive" may be adopted as a solution to the problem of extended battery life if the gains in performance are of an adequate magnitude.

2.2. Power and thermal management trends

Effective use of dynamic thermal management is necessary and common in high-performance platforms to reduce the cooling costs. Multiple trigger and response mechanisms that ensure the thermal solution are not designed for statistically insignificant worst case events (i.e., non-realistic scenarios) have been discussed in Ref. [7]. Similar design techniques can also be utilized in battery life limited systems to dynamically trade off performance against power. Some of the trigger mechanisms include feedback from temperature sensors, on-chip activity counters, dynamic profiling analysis, and compile-time insertion of dynamic thermal management instructions. Among the response mechanisms are voltage and frequency scaling, decode throttling, speculation control, and I-cache toggling. For example, the frequency and voltage scaling scheme reported in Ref. [8] yields a 50% power reduction but limits the performance impact to 20% for the duration of the event.

It is expected in the future that adaptive thermal management will allow thermal solutions to be integrated into a closed loop system with silicon triggers, such as temperature sensors, that then respond dynamically to the requirements of a particular application for maximum efficiency and reliability. Fan speed control [9], and Enhanced Intel Speedstep® [10] technologies are examples of this thrust.

2.3. Use of renewables for power management

Scavenging energy from renewable sources in the vicinity of the computing system is conceptually the best method for extending on-board power and thus extending battery life. A significant challenge with small-scale renewable sources is the low efficiency associated with significantly stepping up the low voltage output to allow integration with the system battery. In an extreme case, there may not be a net benefit in on-board power extension after accounting for the power dissipation in the required converter. The problem is compounded when scalability to multiple sources with different characteristics and intermittent properties are considered. To address this challenge, an efficient conversion system was developed to convert low, intermittent voltage levels to an appropriate system dc-bus voltage, using a two level asynchronous Dixon charge pump [4].

Some of the issues related to the development of methods to extract excess heat from the microprocessor with thermoelectric (TE) modules were partly addressed by Solbrekken et al. in Ref. [11]. The modest energy extracted was sufficient to power a small custom-cooling fan to maintain the junction temperature of a 25 W component under 85 °C. Energy storage was not viable due to the power electronics limitations and required auxiliary kick-start circuitry. In their work, a constant heat source was used in the demonstration experiments in lieu of an actual, dynamic microprocessor. The thermal efficiency cost of the integrated TE module under the heat sink was estimated as a 10–15 W reduction in cooling capacity. The lower cooling capacity can