Demo: A Hardware Platform for Separating Energy Concerns in Tiny, Intermittently-Powered Sensors

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ABSTRACT

Energy harvesting is an indispensable mechanism of sensor devices that operate in perpetuity. While harvesting free energy from the environment has enabled many applications, it has also spawned new problems, and new paradigms. Notably, making decisions on when to use high power sensors and external components when energy is scarce, and future supply is unpredictable. Because sensor nodes generally share a single, centralized energy store, seemingly atomic, or unrelated sensing tasks can hamper each other by drawing the supply voltage too low, and draining the energy reservoir.

This demonstration presents the United Federation of Peripherals (UFoP), a novel method of separating energy concerns in hardware by allocating dedicated energy storage (in the form of small capacitors) to specific sensor components, and charging them in a prioritized fashion with an analog front end. UFOP gives application designers a more deterministic view of energy and task scheduling, allowing them to make better informed decisions when developing sensor applications. Designers do not have to rely on crude estimates or simulations but can instead depend on in-situ analog measurements to opportunistically drive their applications.

Categories and Subject Descriptors

C.3 [Special-Purpose and Application-Based Systems]: Micro-processor/microcomputer applications

General Terms

Reliability, Measurement, Performance

Keywords

Energy Harvesting; Federated Energy; Task Coupling; Capacitor; Embedded System

1. FEDERATING ENERGY

Traditional sensing systems rely on a single energy source such as a battery, or super-capacitor, that powers all system components (*e.g.*, processors, sensors, radios and other peripherals). This

paradigm works well when energy reserve are large, and power failures are rare. However, for intermittently powered sensing devices [1, 2, 4–6] that live off harvested energy and die frequently, this approach can be prohibitive.

We propose a new federated approach to storing harvested energy that separates energy concerns, making it difficult for different system components to starve each other. Our approach, called UFOP (United Federation of Peripherals), uses individual per-peripheral energy stores in the form of small capacitors and low-power control circuitry to isolate and prioritize individual peripherals. Federating energy storage allows power-hungry operations to proceed without sacrificing the device’s immediate ability to use other peripherals, gather new data, process incoming data, and respond to incoming stimuli. This approach also simplifies the task of programming energy-aware logic—effectively replacing complex modeling of analog circuit behaviors with simple binary decisions based on whether or not a peripheral is available.

Our initial implementation of the UFOP approach uses ultra-low-power comparators to control and prioritize the charging of individual energy stores, where the microcontroller gets the first priority. The main capacitor charges until it reaches 2.7 V, then the microcontroller turns on. When the input voltage reaches 3.1 V, the peripheral capacitors charge. Application designers can monitor these voltages to know when a peripheral becomes available.

2. SYSTEM ARCHITECTURE

Figure 1 shows a UFOP system that is integrated with two commonly used peripherals in sensing applications (*i.e.*, a sensor and a radio). The system consists of four main components: an energy harvester, charging controller, peripheral controller, and peripherals. The energy harvesting device harvests ambient energy and stores it in the first-stage capacitor. The charge controller is responsible for turning on and off the microcontroller and charging an array of peripheral capacitors. The peripheral controller turns on and off peripherals (sensor and radio), which are only available when their capacitors are charged.

Energy Harvesting: The UFOP system is powered by ambient sources. The energy harvester converts free energy from the environment (*e.g.*, solar, thermal, radio frequency (RF), and kinetic energy) into electrical energy (DC), which the harvester supplies to the rest of the system. From the harvester, the current first flows to charge first-stage capacitor that powers the microcontroller.

Charging Control: UFOP uses low-power control circuitry as charge controller to control and prioritize the charging of an array of capacitors as well as turning on and off the microcontroller. UFOP is designed with the microcontroller as a first power priority. A sensor without a microcontroller could not process data, and

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Figure 1: Overview of UFoP when integrated with a set of commonly used peripherals; a sensor, and a radio. A UFoP system is made up of four components: an energy harvester, charging controller, peripheral controller, and peripherals. The charge controller manages the charging of an array of capacitors (drawing from the first-stage capacitor) as well as turning on and off the MCU. The peripheral controller (an MSP430FR5739) gates power to the peripherals, allowing peripherals to be completely off when not in use. Peripherals and the MCU communicate independently of the charging controller.

a radio without a microcontroller would have no signal to transmit. From an implementation perspective, this is ideal since the microcontroller can then be used to control the power flow to the peripherals based on application requirements.

Peripheral Control: The peripheral controller in the UFoP system can be any ultra-low-power microcontroller. The FRAM series of MSP430 are work especially well in this function. When the first-stage capacitor capacitor charges up to 2.7 V, the microcontroller turns on. The microcontroller gates power to the peripherals, allowing peripherals to be completely off when not in use. This control communication is independent from the charging control scheme. The switches in the peripheral controller are designed to open (disconnect) when the microcontroller loses its power and turns off, *i.e.*, when the main capacitor's voltage falls below 1.8 V. This design satisfies the MSP430FR5739 supply voltage requirements, *i.e.*, 1.8 V to 3.6 V.

Peripherals: Two most commonly used peripherals in sensing applications are sensor and radio. The type of the peripherals and the tasks they perform determine the size of the capacitors used. When an application uses a lightweight sensor and a radio, the size of the capacitor for the sensor should be a lot smaller than that for the radio. If the application requires intensive data transmission, the radio's capacitor size must be large enough to support the tasks. In the UFoP system, the peripherals are only available when their dedicated capacitors are charged.

3. DEMONSTRATION DESCRIPTION

This is a demo of an associated paper presented at SenSys'15 [3] which contains a more detailed description of the system. We show

the difference between a centralized energy system and a system that uses UFoP. Each system is equipped with a small solar panel, a LED flashlight is used to generate light. The availability of the MCU and each peripheral (a sensor and radio) are shown with LEDs as well as graphically on a display. This highlights the differences in each approach, and the benefits of using UFoP.

4. CONCLUSION

This demonstration presents UFoP, a federated approach to energy storage for intermittently-powered sensors. UFoP allows application developers to separate energy concerns in a system; with a dedicated energy store for each component. Sensors, radios, and other peripherals become independent of each other, allowing for simpler decision making, and guaranteed outcomes. UFoP increases availability, energy harvesting efficiency, and resiliency to programmer error.

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