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Demo abstract: Simultaneous energy harvesting and sensing using piezoelectric energy harvester

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Demo Abstract: Simultaneous Energy Harvesting and Sensing using Piezoelectric Energy Harvester

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ABSTRACT

With the capability to harvest energy from low frequency motions or vibrations, piezoelectric energy harvesting has become a promising solution to achieve battery-less wearable system. Recently, many works have convincingly demonstrated that PEH can also act as a self-powered sensor for detecting a wide range of machine and human contexts, which suggests that energy harvesting and sensing can be performed concurrently. However, realization of simultaneous energy harvesting and sensing (SEHS) is challenging as the energy harvesting process distorts the sensing signal. In this demo, we propose a novel SEHS architecture prototyped in the form factor of an insole, which combines energy harvesting and sensing in the same piece of PEH. Meanwhile, a special filtering algorithm is applied to minimize the distortion in the sensing signal.

This demo complements the paper "SEHS: Simultaneous Energy Harvesting and Sensing using Piezoelectric Energy Harvester" to be presented at IoTDI'18.

CCS CONCEPTS

•Human-centered computing → Ubiquitous and mobile computing; •Computer systems organization →*Architectures;* Embedded and cyber-physical systems;

KEYWORDS

Piezoelectric Energy Harvesting, Simultaneous Energy Harvesting and Sensing, Context Detection from Energy Harvesting

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1 INTRODUCTION

Piezoelectric energy harvesting (PEH), which converts motion, stress, or vibration into usable electrical power, has become an attractive solution to power many industrial sensor nodes [1]. An interesting recent development confirms that PEH can serve not only as a source of ambient power, but also as a sensor for detecting a wide range of machine and human contexts, such as measuring the air flow of heating and air conditioning systems [2] and detecting the activities of daily living [3]. These findings suggest that the same PEH hardware could be potentially used for simultaneous energy harvesting and sensing (SEHS), offering a new design space for low cost and low power electronics for the rapidly growing Internet of Things of market.

Unfortunately, realization of SEHS faces practical challenges arising from the interactions between the energy harvesting and sensing processes. In particular, when a capacitor is used to store the harvested energy from the PEH hardware, the dynamic states (stored energy) of the capacitor modifies the current or AC voltage signal generated by the PEH. Since context detection relies on the AC voltage signal of the PEH, its modification degrades the sensing or context detection performance of the PEH.

The focus of this demo is to devise solutions that enable use of the same PEH hardware for both energy harvesting and high quality sensing. In particular, we propose and demonstrate that high quality sensing for SEHS is achievable by using capacitor samples to filter out the impact of the capacitor on the AC sensing signal. On the one hand, the outcome directly reduces the cost and complexity of a SEHS system as separate PEH elements are no longer required for energy harvesting and sensing. On the other

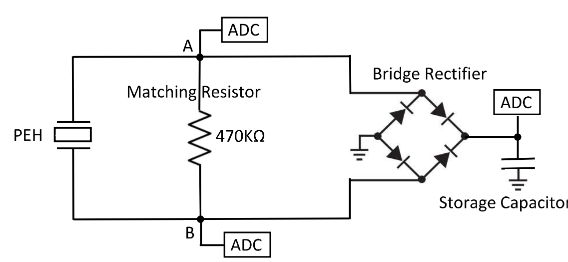

Figure 1: Circuit design of the proposed SEHS architecture

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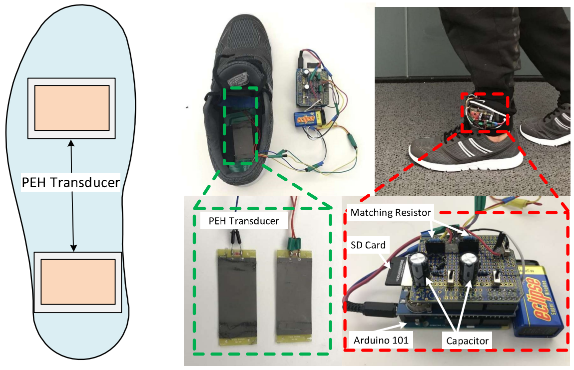

(a) Insole Model (b) Subject Walking

Figure 2: The Design and Appearance of the prototype

hand, total energy harvesting capacity can be increased when two PEHs are used, because both of them can harvest energy. On the same token, context detection accuracy can be increased when two PEHs are used, because both of them can act as sensors providing multiple sensing signals.

2 SYSTEM IMPLEMENTATION

2.1 Hardware Design

The aims of the SEHS design are to (1) store the harvested energy, i.e., the rectified AC voltage generated by the PEH, in a capacitor, and (2) read the same AC voltage for context sensing using minimal power consumption. Figure 1 shows the circuit design of the proposed SEHS architecture. A matching resistor is used to limit the peak amplitude of the AC voltage within the ADC readable range. Instead of using a single ADC channel to capture the whole AC waveform [2, 3], we use two ADC channels, i.e., point A (V_A) and point B (V_B), to measure the voltage on the matching resistor. Since the two points are directly connected to the output of PEH, the generated voltage, V, can be easily derived by subtracting the measured voltage at point B from point A (both are non-negative values), i.e., $V = V_A - V_B$. The energy flows to the capacitor through a full-bridge rectifier which is used to convert the AC voltage to DC voltage. With this circuit, the proposed SEHS architecture is able to collect the voltage signal and store the generated energy by using the same piece of PEH hardware.

Figure 2 shows the prototype we designed and implemented in the form factor of a shoe to harvest energy during human walking and detect the user gait at the same time using the PEH voltage signal. To explore the potential performance improvements compared to the state-of-the-art, the prototype includes two PEHs from Piezo System [4] mounted on the front and rear of the insole. AC voltages from the PEHs are rectified by full-bridge diodes rectifier and charged into two $220\mu F$ electrolytic capacitors. The output voltage and capacitor voltage are sampled by an Arduino UNO board. A sampling rate of 100Hz is used for data collection and the sampled data is saved on a 4GB microSD connected to the Arduino using a microSD shield. A nine volts battery powers the whole system. To help users collect data, the prototype contains three switches, one is to control the start and stop of data collection and the other two for controlling the charging and discharging of the two capacitors respectively. The entire Arduino board is placed outside the shoe.

2.2 Data Processing

When a capacitor is used to store the harvested energy, its dynamic states (stored energy) modifies the current or AC voltage signal generated by the PEH. Specifically, the peak-to-peak amplitude of the AC voltage is increasing with time as the capacitor voltage rises, i.e., more energy is being stored. The similar phenomenon is also described in [2]. Thus, we propose a filtering algorithm which is able to prevent the increasing capacitor voltage from lifting the AC voltage without destroying the pattern of the signal. In terms of different context sensing applications, distinct methods can be applied to the voltage signal. For example, step counting can be achieved by detecting the peaks from the sensing signal and different features should be extracted to recognize various activities with machine learning methods.

3 DEMONSTRATION DESCRIPTION

On this demonstration we will bring the insole based prototype as well as a laptop with MATLAB for real-time data display. The Arduino UNO board is connected to the laptop via wire and the sampled data is transmitted through serial communication. Since the demonstration of gait recognition requires multiple subjects to walk for several minutes wearing the shoes, we conduct this demonstration through asking the subjects to press the PEH in different ways, thereby illustrating the context sensing capability of PEH. Overall, the demonstration is divided into the following two parts:

- A video record of our experiments with several subjects will be played during the demo to exhibit the energy harvesting and sensing process. In addition, we will demo through this video that by using the sensing signal we can achieve gait recognition with high accuracy [5].
- We will also provide our prototype during the demo session, which allows conference participants to test and experience the procedure of simultaneous energy harvesting and sensing. The participants can either press the PEH with their hands, or they can attach the PEH insole inside their shoes to walk. We will display the harvested energy and the sensing signal in real-time via MATLAB.

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