Demo Abstract: Motion-powered Gameboy

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ABSTRACT

Energy harvesting technology enables the battery-free realization of some sensing, computing, and connectivity functions. However, its promotion in battery-free human-computer interaction is relatively slow in comparison. There is a critical energy gap around interactive devices which are screen-focused and usually power-hungry. This energy gap can be narrowed down and filled up by selecting a proper display and taking a sophisticated hardware and software co-design. Motion-powered gameboy, the first robust personal mobile gaming device, is manufactured by combining the features of a bistable E-ink display and a quasi-static toggling motion energy harvester. With the hardware-software co-design, the amount of energy generated by the player's pinch action can adequately guarantee successful user interaction and preferable user experience. The design methodology of the motion-powered gameboy provides a valuable example for the development of motion-powered human-computer interactive devices.

KEYWORDS

Battery-free IoT, human-computer interaction, motion energy harvesting

1 INTRODUCTION

Human-computer interaction (HCI) electronics are generally screen-centered. Most standard display technologies rely on a sustained power supply. The display images disappear upon power failure. There are also some bistable displays, e.g., E-ink and mechanical dot matrix, which can hold the image permanently after being powered off. Thus, a bistable display can be a potential device to achieve battery-free HCI. Another challenge that battery-free HCI devices face is responding to the player's actions. For example, upon clicking the key 'Enter,' a 'Hello, world!' should be printed on the screen. Utilizing ambient energy to power electronic devices without using chemical batteries has been an open research topic during the last decade.

Methods of harvesting energy are widely discussed for decentralization and reducing maintenance costs. The ambient energy sources include solar, radio frequency (RF), and mechanical vibrations. Most of the energy harvesting processes rely on the accumulation of continuous power income. The power-ready and action time is unpredictable. When it comes to the scenario of HCI, an unknown delay in response to the player's action is not acceptable. In a recently proposed solar-powered game console, the player might have to wait for energy collection before the resurrection from a checkpoint[1]. On the other hand, there exists a special type of mechanical energy harvester called a quasi-static toggling (QST) harvester, with which the amount of energy harvested from a toggling action is more or less the same. Such a QST energy harvester can simultaneously provide a reliable energy supply and act as a command button. To realize this goal, we must carry out some co-design among the QST harvester, power conversion circuit, and embedded software, such that a zero-delay screen refresh can be realized in response to each finger action.

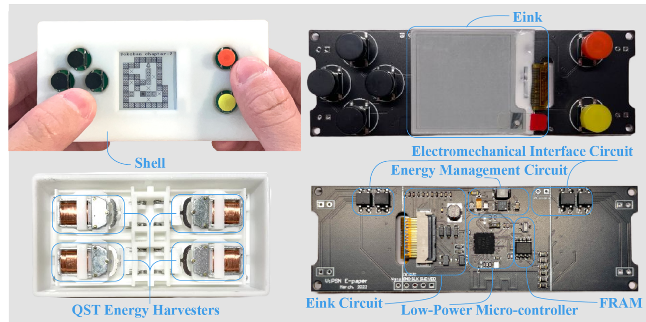

Figure 1: Hardware Prototype.

This demo will introduce the design concept and prototype of this motion-powered gameboy. In particular, the mechanical and electrical hardware and software co-design is emphasized. The solution presented in this demo can be applied to other atomic operations with relative high energy consumption.

2 IMPLEMENTATION

2.1 Hardware

QST Energy Harvester: A QST energy harvester can scavenge the energy associated with transient or low-frequency motions. It benefits from the mechanical potential energy pre-charging process, in which the generated energy can be adjusted by pre-designing the mechanical structure[2]. Four commercial off-the-shelf (COTS) PM5600 harvesters are utilized to power the embedded system. Voltage pulses are generated whenever the harvesters are toggled between the two stable points, which correspond to two valleys in the potential well picture.

Electromechanical Interface Circuit: A full-wave bridge rectifier is used to convert the input bipolar and pulsed power into stable dc output, such that the digital system can be energized properly for a required short interval. A single PM5600 module can at least generate 1.2 mJ of energy in every hand click.

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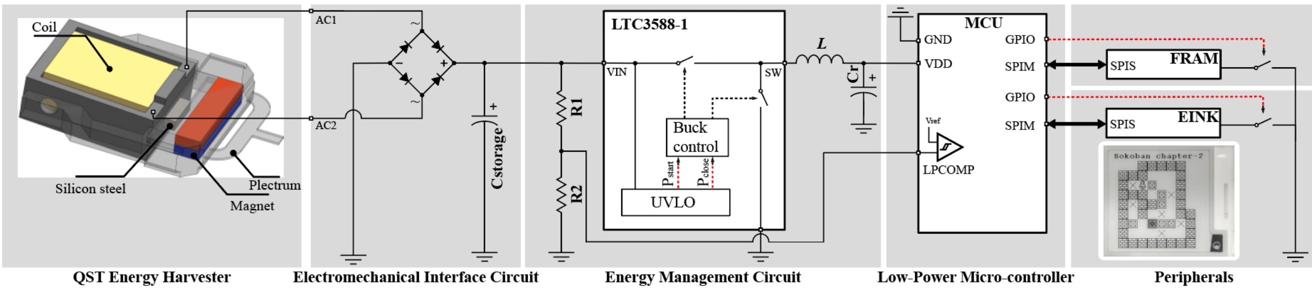

Figure 2: The architecture of motion-powered gameboy.

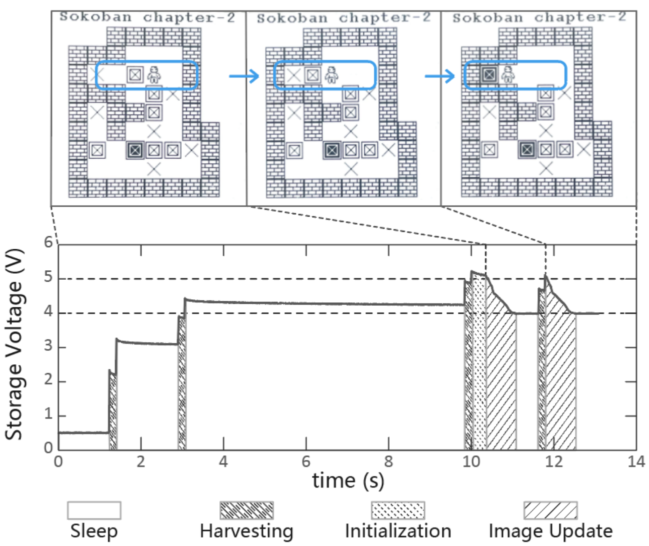

Figure 3: Experimental work cycle.

Energy Management Circuit: A COTS buck converter IC (LTC-3588 by Analog Device Ltd.) is used for energy management. The input charge is accumulated in the storage capacitor until it reaches the 5 V threshold. After that, the accumulated energy will begin to be transferred to the output at a constant digital voltage level. As shown in Fig. 2, the voltage level can also be informed to MCU through a low-power comparator.

Low-Power Micro-controller: An Arm Cortex-M4F SoC (nRF52832 by Nordic Ltd.) is used to provide computational capabilities.

Peripherals: A low-power COTS 1.54-inch E-ink module (GDEH-0154D67) is used as the display. A FRAM IC (MB85RS256) is used as the non-volatile memory. Both peripherals are connected to the SoC over the SPI interface. Since these peripherals were not optimized for battery-free applications, their operation flow should be treated as energy-costly atomic tasks.

2.2 Software

When electronics work under the battery-free constraint, they might not work persistently. It brings difficulties to the design of battery-free nodes. There are many state-of-the-art techniques (QuickRecall, Hibernus, Mementos, and MPatch, et al.) published for enabling a system to perform reliable computation spanning over power outages. Since an interactive process must be regarded as an atomic task for ensuring a good user experience; the task-based checkpointing method is preferred in this application. The system should be able to set checkpoints in between interactive tasks; save a snapshot to FRAM before the power is used up and restore it from FRAM when the gameboy is activated again.

In general, in an energy-aware system, energy consumption must be reduced. Without any modification to the driver, a single frame update costs more than 72.7 mJ, which is too much and requires many QST modules to supply such an amount of energy. Four steps are taken to reduce the power consumption:

1. Use interrupts to wake up the usually hibernating processor;
2. Adjust the interrupts and parameters in SPI protocol;
3. Use MOSFET switches to turn off the unused peripherals;
4. Optimize the state machine and peripheral operation flow.

After software optimization, the energy consumption of a single interactive refresh is reduced from 72.7 mJ to 4.5 mJ, more than 16 times less.

2.3 Co-design

According to the energy demand, four QST energy harvesters are used to build the mechanical part, as shown in Fig. 1(left). A 1 mF capacitor is chosen as the storage, and its storage kick-off threshold is set to 5 V, so the system can work around the maximum power point. Furthermore, a lever structure is used to reduce the toggling force and maintain comfortable manipulation.

3 DEMONSTRATION

To demonstrate the functionality of the motion-powered gameboy, two hand pinches are needed to lift up the storage energy level. Then, the player should click one of the input buttons with one hand pinch. After that, the device will be powered on, finish an essential initialization, interactively refresh the screen, and enter sleep mode. The interactive process would be activated again until the next hand pinch. As shown in Fig. 3, the energy generated by player's action can sufficiently satisfy the demand of motion-powered Sokoban game.

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