Demo: SOCRAETES: SOlar Cells Recorded And EmulaTed EaSily

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Abstract

We propose SOCRAETES, a simple to replicate tool used for recording and emulation of energy harvesting environments. SOCRAETES aims at aiding with repeatable experimentations during the design and evaluation of energy harvesting devices. The tool is particularly designed with the goal of avoiding complex hardware circuitry. This will allow researchers and hobbyists with little prior experience in electronics to replicate the work, and by doing so benefit from the insights such a tool provides for the design and evaluation of energy harvesting systems. The current implementation of SOCRAETES can measure and emulate solar cell voltages and currents in the range of 0-6.5 V and 0.5-55 mA, respectively. Moreover, the range of measurement and emulation can be modified for specific energy environments and harvesters by utilizing different passive components. This will, in turn, result in higher overall achievable accuracy.

Keywords

Energy harvesting, Intermittent computing, Batteryless, Solar cell, I-V curve, Recording, Emulation

1 Introduction

In the past few years, the area of energy harvesting devices has drawn significant attention from the research community. This attention has been especially prominent in the fields of wireless sensor networks and IoT. The reason is that not only do such devices need portable energy sources for their operation, but also they are in many cases intended for large-scale deployments, with several nodes distributed over a large area. This attention seems to be well justified in the light of the newest findings in the field of wireless sensor networks. During long-running deployments of several sensor nodes, it has been found that one of the important factors negatively affecting the reliability of such systems in practice is the use of conventional batteries as the energy storage [1].

Table 1. Performance Characteristics of SOCRAETES

Recording	Voltage Range	0 - 6.5 V
	Current Range	0.5 - 55 mA
	Voltage Mean Error	1.28%
	Current Mean Error	1.49%
Emulation	Voltage Range	0 - 6.5 V
	Current Range	0.5 - 55 mA
	OC Voltage Mean Error	0.2%
	SC Current Mean Error	2.36%

In addition, issues such as the environmental impact of using large numbers of batteries and possibly the replacement of them provide further motivation for investigating alternative approaches more in-depth.

Since energy harvesting systems operate under nondeterministic conditions in terms of the available energy, their system design requires special attention to prevent unforeseeable conditions from rendering the system unstable. This makes repeatable and reproducible experimentation conditions both during design and also evaluation of these systems a very important requirement. Accordingly, useful tools have been introduced for tackling the issue of capturing and emulating energy harvesting environments in a repeatable manner. Ekho [5] and Shepherd [3] have been two of the most influential tools in this area, but require highly sophisticated, custom-designed hardware for operation. SunaPlayer [2] is capable of emulating a large range of solar cell voltage and currents. However, it also consists of sophisticated hardware components, and is capable of emulation of solar cells only. Light-box approaches, such as the solution introduced in [4] can be used for repeatable experimentation with solar cells, but they, too, focus solely on emulation of solar cells, and also require custom hardware setups.

While the mentioned tools have been very innovative and useful for addressing the design and evaluation of energy harvesting systems, they rely on highly sophisticated, custom-designed hardware for their operation. We feel that in many cases, such hardware is not accessible to all researchers or even interested hobbyists, particularly those who are not very familiar with or experienced in hardware aspects such as assembling sophisticated printed circuit boards. This issue might prevent some researchers from entering the field of energy harvesting devices and investigating their ideas in this area. Therefore, we introduce SOCRAETES, a simple to replicate solar cell recording and emulation tool that can be reproduced with a minimum of readily-available, off-the-shelf hardware components. More-

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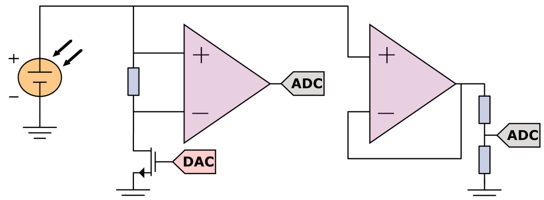

Figure 1. High-level schematic of the recording circuit.

over, the components used for this tool are available in through-hole packages, which makes it possible to build the required hardware on solderless breadboards, or preferably, on prototyping boards.

SOCRAETES can, therefore, support the task of design and evaluation of energy harvesting systems in a simple and affordable manner. The current hardware setup of SOCRAETES costs around 80 €, including a Teensy 3.6 development board, passive and active components, and wiring and connectors. Table 1 depicts the performance characteristics of the current implementation of this tool.

2 Design

SOCRAETES consists of two building blocks, namely those pertaining to the harvester recording and the harvester emulation functionalities.

The current implementation of SOCRAETES focuses on solar cells as the energy harvester. The solar cell recording functionality follows a converter-less approach since omitting a converter provides a more direct access to the harvester and therefore, the energy environment. The energy available to the solar cell is characterized by sweeping the operation points of the solar cell using a MOSFET in an open-loop configuration. This is followed by measuring the solar cell's voltage and current at each point. This procedure leads, in turn, to the capturing of the I-V curves characteristic of photovoltaic cells. The captured curves are then transmitted to a host PC over the serial interface for storage and later analysis and emulation. By utilizing a MOSFET for sweeping the operation points of the solar cell, SOCRAETES can handle a high range of harvester currents and voltages. Figure 1 depicts the high-level schematic of the recording circuit.

The harvester emulation functionality is based on an equivalent-circuit model approach. Accordingly, the emulation is carried out by utilizing a single-diode model of photovoltaic cells [6]. This is in direct contrast to works such as Ekho, where the emulation is done by measuring the operation point of the load in short time intervals, and emulating the necessary voltage or current accordingly [5]. While such a measure-and-emulate approach potentially offers a high level of flexibility in terms of the different types of energy harvesters that could be emulated, it requires sophisticated custom-made electronic circuitry for reliable operation. On the other hand, by adopting a model-based emulation approach, we aim at reducing the complexity of the required hardware, and therefore a lower entry-barrier for both researchers and hobbyists to start investigating the area of energy harvesting systems using solar cells.

In addition to the less complex electronic circuitry, adhering to a model-based emulation approach has the advantage of high electrical reliability. This is the case in particular during edge cases, such as harvester short circuits, without relying on very high speed and accurate circuitry. Instead the inherent characteristics of the model are exploited to ensure expected emulation behavior. This point is important for making sure that the results acquired by means of emulation can also be seen as reasonable depictions of the real harvesting conditions.

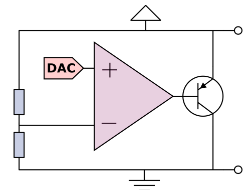

Figure 2. The transistor approach used for setting the open-circuit voltage of the emulated solar cell.

Our emulation circuit for a solar cell consists of a voltage-controlled current source, a diode-equivalent circuit, and parasitic resistors. The short-circuit current of the emulated solar cell is controlled by the voltage-controlled current source, while the open-circuit voltage of it is controlled by the diode-equivalent circuit. The diode-equivalent circuit consists of a PNP transistor, biased by the output of a digital-to-analog converter, as depicted in Figure 2. This allows regulating the forward-voltage of the diode-equivalent circuit, which will then facilitate the manipulation of the open-circuit voltage of the emulated solar cell.

3 Conclusion and Future Work

During the demonstration, solar cells attached to SOCRAETES will be used to capture I-V curves based on the illumination of the demonstration environment. Furthermore, various energy traces of different energy harvesting conditions will be emulated by SOCRAETES and can be measured by tools such as a multimeter or oscilloscope.

In the future, SOCRAETES can be extended with a custom PCB for increased accuracy and lower measurement noise. Moreover, various energy harvesting traces can be captured and made available to support the community in the design and evaluation of energy harvesting systems.

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5 References

[1] M. Afanasov et al. Battery-less zero-maintenance embedded sensing at the mithræum of circus maximus. In *Proc. of the 18th Conf. on Embedded Networked Sensor Systems (SenSys)*, page 368–381, 2020.

[2] S. Bobovych et al. Sunaplayer: high-accuracy emulation of solar cells. In *Proc. of the 14th International Conf. on Information Processing in Sensor Networks*, pages 59–70, 2015.

[3] K. Geissdoerfer et al. Shepherd: A portable testbed for the batteryless iot. In *Proc. of the 17th Conf. on Embedded Networked Sensor Systems (SenSys)*, page 83–95, 2019.

[4] L. Hanschke et al. Light in the box: Reproducible lighting conditions for solar-powered sensor nodes. In *Proc. of the 15th ACM Conf. on Embedded Network Sensor Systems*, pages 1–2, 2017.

[5] J. Hester et al. Ekho: Realistic and repeatable experimentation for tiny energy-harvesting sensors. In *Proc. of the 12th ACM Conf. on Embedded Network Sensor Systems (SenSys)*, page 330–331, 2014.

[6] S. Shongwe et al. Comparative analysis of different single-diode pv modeling methods. *IEEE J. of photovoltaics*, 5(3):938–946, 2015.