Demo Abstract: Powering an E-Ink Display from Soil Bacteria

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ABSTRACT

This demo showcases the power delivery potential of soil-based microbial fuel cells. We build a prototype energy harvesting setup for a soil microbial fuel cell, measure the amount of power that we can harvest, and use that energy to drive an e-ink display. Microbial fuel cells are highly sensitive to environmental conditions, especially soil moisture. In near-optimal, super moist conditions our cell provides approximately 100 µW of power at around 500 mV, which is ample power over time to power our system several times a day. In sum, we find that the confluence of ever lower-power electronics and new understanding of microbial fuel cell design means that "soil-powered sensors" are now feasible. There remains, however, significant future work to make these systems reliable and maximally performant.

This demo is a working copy of the system presented at LP-IoT'21 [6].

CCS CONCEPTS

• **Hardware** → *Renewable energy*; *Platform power issues*; *Emerging architectures*.

KEYWORDS

microbial fuel cell (MFC), biobattery, energy harvesting, low power

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1 INTRODUCTION

Power is a perennial challenge for real-world sensor deployments. To support scale, devices need to last long periods of time with little to no supporting infrastructure or maintenance. Existing wide-area sensing systems rely on batteries or harvest the required energy, most often from solar or wind sources. One problem with solar, wind, and other common sources of power is that they are not always available or reliable. This has led to growing interest in new, non-traditional energy scavenging sources.

The burgeoning set of low-power energy harvesting chips now available can harvest power from voltage sources as low as 25 mV.[1] While most of these energy harvesters target thermoelectric, piezoelectric, RF, and solar energy sources, their ability to extract power from low-voltage sources facilitates the exploration of novel energy sources, like tree trunks [2], and the re-visitation of old ideas, such as microbial fuel cells (MFCs). MFC harvesting has been studied in wastewater management [1, 4, 9], but there has not been a similar focus for soil MFCs. We re-examine the viability of soil MFCs to produce sufficient power to be useful for sensor applications. Specifically, due to the low but relatively constant power available, we find that soil MFCs may be a good fit for the new "reliable but intermittent" sensor class [2].

MFCs are made of electrogenic bacteria that release electrons as they metabolize their food. Normally, these bacteria use metals in the soil as electron acceptors, but they will readily colonize an electrically conductive anode, allowing us to capture the electrons they expel. As the source of power is the activity of living organisms, MFC performance can vary drastically based on local environmental conditions. Towards real-world applications, then, this demo is just step one. We explore a best-case soil MFC to see if it is capable of powering modern sensors. We see a long line of exciting future work towards the question of what it would take to realize viable and reliable soil MFCs everywhere.

Before diving in, we wish to draw distinction between MFCs as a new energy scavenging opportunity versus MFCs as a new "renewable" energy source. Logan et al. [5] argue for the standardization of terminology when describing MFCs. Specifically, unless the medium or nutrients that an MFC uses to generate electricity are refreshed somehow, the apparatus should be referred to as a *biobattery* rather than a fuel cell. The cell we use in this demo is self-contained, thus a biobattery. We will refer to it as such.

2 DESIGN AND IMPLEMENTATION

Figure 1 provides an overview of the architecture and realization of our prototype system. For our biobattery we use a commercial off-the-shelf Mudwatt that uses galvanically inert carbon felt electrodes [3]. We use commercial soil with known parameters for our cell (Figure 1c for details)

To grow the initial colony, we follow the instructions provided by the Mudwatt. We place 1 cm of soil in the container and then install the anode at that level. We then bury the anode below an additional 5 cm of soil. Finally, we place the cathode on top of the soil, where it is exposed to the ambient air. The Mudwatt required approximately three weeks of constant watering to mature and produce consistent power.

After reaching maturity, with a constant 2.2 kΩ load our Mudwatt produces 100 µW of power in steady-state. The peak open-circuit voltage we observe is around 700 mV. This limits the energy harvesters we can use. Following the 2021 survey done by Jagtap [2], we choose an ADP5091 development kit to harvest power

[1] Examples include the MCRY12-125Q-42DI and related chips from MATRIX.

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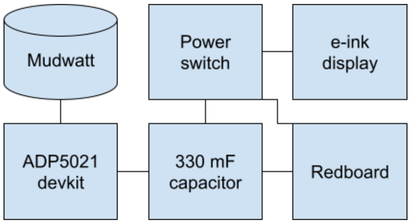
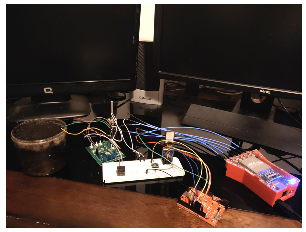


(a) Prototype block diagram.



(b) Prototype system.

Biobattery	Magical Microbes Mudwatt [7]
6 cm soil	Miracle-Gro: Cactus, Palm, & Citrus Potting Mix 0.06% total nitrogen, 0.02% P_2O_5, 0.04% K_2O
Harvester	ADP5091-1-EVALZ
Supercapacitor	FMC0H334ZF (330 mF)
Microcontroller	SparkFun RedBoard Artemis
Power switch	TPS22860DBVR
E-ink interface	DESPI-C102
E-ink display	GDEW0102I3F, 1.02 inch display
Precision logger	RocketLogger [8]

(c) Components used to build prototype system.

Figure 1: Prototype Overview & Implementation. In (b), from left to right: the Mudwatt, the AD5091 harvester development kit, the supercapacitor, the e-ink display and power switch, the Redboard Artemis, and the RocketLogger.

from the Mudwatt. We configure the ADP5091 to have its main boost enabled, the regulated out voltage set to 2.5 V, the LDO mode enabled, the boost mode on, the regulated output enabled, and the MPPT sensing function enabled and in the dynamic mode.

We use a 330 mF supercapacitor as our energy store. We choose a supercapacitor for its nearly unbounded cycle count as well as being able to tolerate non-constant voltages when charging.

We select the Redboard Artemis for our microcontroller as it features an Ambiq Apollo3 MCU. In principle, the Apollo3 draws just 3 µW when in deep sleep.

We use an e-ink display screen refresh as a representative example of a periodic high-energy task sensors might undertake. E-ink displays draw little to no power when holding an image, but they consume an appreciable amount of energy to refresh their display. For instance, our display, per its datasheet, draws a maximum of 40 mW over four seconds to refresh its display. As the e-ink display controller is not optimized for deep sleep performance, we add a power switch to explicitly disconnect power to the e-ink display when not in use. Originally, we did not intend to include a dedicated power switch to gate power to the e-ink display. However, initial testing showed that the display was not shutting down as expected, thus necessitating the removal of its power supply externally.

Figure 1b shows our actual prototype. The Mudwatt is connected to the `VIN` and ground terminals on the ADP5091 development kit, and the supercapacitor is connected to the battery terminals of the harvester.

We have uploaded the firmware for our prototype to Gitlab.[2] The firmware manages the e-ink display and the power state of the e-ink and the microcontroller. During a power-on event, the firmware first performs a full-screen refresh by enabling power to the display, sending framebuffer data to update the display with the state of the internal RTC, and finally initiating the actual refresh. The limited communication interface to the e-ink display requires polling the busy line to detect when refresh completes. This results in higher-than-anticipated power draw for the MCU during operation. A full event takes approximately four seconds to complete.

After the screen redraw, we turn power off to the e-ink display and instruct the Redboard to enter its deep sleep mode. An internal timer fires 20 seconds later to wake up the Redboard and repeat the program. The board repeats this operation until the energy reserves are depleted.

We generally attempt to keep the biobattery in optimal conditions. When not running the experiments testing the impacts of the Mudwatt drying out, we add water to the Mudwatt on an almost daily basis to ensure the anode remains in an anaerobic condition. We also let the Mudwatt rest for an hour every other day to ensure the biobattery remains in peak operating condition.

3 DEMONSTRATION

The demo consists of one Mudwatt biobattery on a bench, attached to an energy harvester with a super capacitor for energy storage. Once the super capacitor is charged, we switch the super capacitor from charging to supplying power to the connected microcontroller, which drives an e-ink display. The e-ink display displays a semi-arbitrary time from the microncontroller's RTC in the format `HH:MM:SS`. We will show the energy harvesting performance with an attached RocketLogger [8] monitoring the storage super capacitor on a screen.

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