# Demo Abstract: DPP3e: A Harvesting-based Dual Processor Platform for Advanced Indoor Environmental Sensing


Luca Rufer
ETH Zurich, Switzerland
lrufer@student.ethz.ch

Naomi Stricker
ETH Zurich, Switzerland
nstricker@ethz.ch

Reto Da Forno
ETH Zurich, Switzerland
rdaforno@ethz.ch

Lothar Thiele
ETH Zurich, Switzerland
thiele@ethz.ch

Andres Gomez
University of St. Gallen, Switzerland
andres.gomez@unisg.ch



## ABSTRACT

Wireless sensors form an integral part of the Internet of Things (IoT), standing at the edge between the cyber and physical domains. Acquiring and transmitting environmental data is an energy-intensive workload, especially when considering networks spanning large buildings or even cities. Many works aim to integrate energy harvesting into wireless sensors, providing them with a greater level of energy autonomy. Initially deployed for energy-rich outdoor environments, recent advances have allowed wireless sensors to efficiently utilize the reduced energy harvested in indoor lighting conditions. This demo introduces a harvesting-based Dual Processor Platform, the DPP3e, designed for energy harvesting in indoor environments. It features various sensors for advanced indoor environmental sensing, e.g. air quality measurements, a low-power display for immediate visual feedback, and a powerful microcontroller for energy-efficient inference of Tensorflow models. Furthermore, it has two separate RF interfaces: a 2.4 GHz Bluetooth Low Energy (BLE) radio for short-range communication, and a sub-GHz transceiver for long-range communication. Using configurable power domains and advanced power management, it can sustain sending BLE packets every 5 seconds while consuming only 37 $\mu$W.



## KEYWORDS

Indoor Energy Harvesting, Internet of Things, Gas Sensing


## 1 INTRODUCTION

The Internet of Things (IoT) is uniquely suited for data gathering on various scales ranging from individual buildings to cities. They can collect data with a high temporal and spatial resolution by scaling the number of nodes in the network. Challenges associated with IoT have been highly investigated for many years and various platforms have been developed to demonstrate research results. These include for example the Dual Processor Platform (DPP) [1] that partitions the application and communication logic into separate microcontrollers, allowing each to have its own timing characteristics. This architecture has been for example implemented in a microseismic platform for natural hazard monitoring [8] and has been employed to demonstrate various communication protocols, such as [4]. SociTrack [2] is another recently developed IoT platform that enables accurate wireless distance measurements. These platforms have been battery-based, meaning their lifetime is limited by the energy they were initially deployed with.

Moving towards energy harvesting-based nodes enables their long-term self-sustainable operation and significantly improves scalability and maintenance. Various harvesting-based platforms with and without batteries have been proposed, examples with batteries include the Permamote [7] and PhyNetLab [3], examples without batteries include the Transient BLE node [9] and the MiroCard [6]. The first two devices have very large energy autonomy, lasting months or years without any input energy. Although certain applications benefit from a battery, it also has drawbacks such as a negative environmental impact and a significant increase in volume and monetary cost per device. Contrary, the latter two batteryless systems buffer very little energy and thus have limited energy autonomy, typically lasting only milliseconds without input energy. Yet, its environmental impact, cost, and size are lower. Our new platform has a supercapacitor for increased energy autonomy in comparison to the MiroCard but not a larger energy storage as a battery-equipped platform, thus trading off their characteristics. This demonstration presents DPP3e, an ultra-thin platform based on the DPP with a limited energy autonomy of several hours, capable of operating with the tightly constrained energy budgets of indoor lighting. A prototype is depicted in Figure 1. The application processor can access multiple indoor air quality sensors. Ongoing research [5] is developing compensation techniques to overcome the variable sensitivity that results from power-cycling chemical gas sensors which is an essential design paradigm in low-power systems. These techniques require large memory and computational power, which have to be present in the application processor. The communication processor uses a long-range transceiver to facilitate wireless data collection. Yet since such indoor environmental sensing applications are human-driven, it is beneficial to also provide users with direct visual access to the deployed sensors. Typically displays are power-hungry components, which are also too costly and bulky to include in the vast majority of low-power wireless

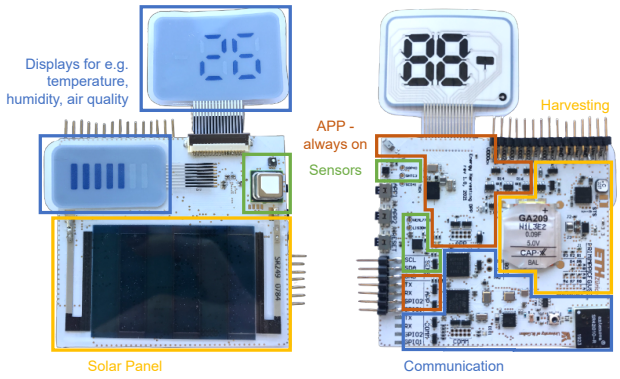



**Figure 1: DPP3e prototype with polarized electrochromic displays.**

sensors. In this work, we utilize a novel, low-cost, ultra-low power electrochromic display to visualize sensor readings.

## 2 DPP3E OVERVIEW

The harvesting-based DPP3e builds on the DPP presented in [1] and is designed for indoor applications. Configurable power domains and advanced power management enable various energy modes with different capabilities that support numerous applications and make efficient use of highly variable harvesting input powers. The platform incorporates a thin-film organic solar cell and energy harvesting circuitry designed for indoor environments. An onboard supercapacitor can store a few Joules of energy when fully charged. This provides an energy autonomy of roughly 10 to 20 hours, depending on the system's energy mode.

An always-on power domain includes the application (APP) microcontroller implemented with the Apollo3 Blue Plus and the low-power display from Ynvisible Interactive Inc. The Apollo3 contains an integrated Bluetooth Low Energy (BLE) radio and uses an external chip antenna. It also controls the two other power domains: 1) sensing, and 2) communication. The sensing subsystem includes an accelerometer, a temperature and humidity sensor, a light intensity sensor as well as a CO2 and volatile compounds concentration (VOC) sensor for gas sensing. The platform's voltage supply has selectable levels to accommodate sensors with distinct requirements. The communication subsystem consists of a stateful processor interconnect [10], an STM32L433 microcontroller that implements the communication stack, and the Semtech SX1262 LoRa transceiver with a chip antenna to enable long-range communication.

## 3 DEMONSTRATION

In this demonstration, we show the DPP3e operating in different modes and characterize their power requirements.

In the most energy-efficient operation mode, the display is updated periodically by the APP processor. The low-power electrochromic display contains a material that, when polarized, can block light and become visible. A display can be composed of multiple segments which are polarized independently. The display only consumes current during the short polarization phase and subsequently, the charge is stored. However, the visibility fades over time and therefore the displayed data needs to be periodically refreshed. The display's average power consumption is very low because it needs to be refreshed seldomly, in the order of minutes. We characterize the current requirement when only the always-on power domain is enabled and the signed two-digit display is updated every minute. A second energy mode has the always-on power domain with the APP processor powered and data is sent with BLE. Figure 2 depicts the resulting power consumption of the DPP3e. The trace features peaks associated with sending BLE packets and with

**Table 1: Characterization of three DPP3e energy modes.**

| Energy Mode | $I_{avg}$ at 1.95 V | Periodicity |
|---|---|---|
| APP Processor & Display | 17.5 µA | 60 s |
| APP Processor & BLE | 18.6 µA | 5 s |
| APP Processor & LWB | 31.6 µA | 60 s |

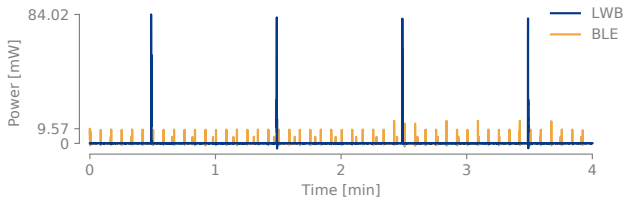



**Figure 2: The DPP3e performs short-range communication (BLE) every 5 seconds or long-range communication (LWB) every 60 seconds. Unused power domains are disabled.**

maintaining FreeRTOS. The third energy mode activates the communication processor for LWB-based data transmission [4]. The DPP3e acts as a node and sends data to an always-on host node. The communication rounds occur every 60 s and the measured power trace is visible in Figure 2. The average power requirement after the initial phase of the protocol is evaluated. These three energy modes are characterized and the results are summarized in Table 1. Various other modes of operation, for example, combinations of the three characterized energy modes, are supported by the platform.

**Summary**. In this demonstration, we present DPP3e, the new harvesting-based Dual Processor Platform. Powered by indoor lighting, this platform has various sensors for indoor air quality monitoring. It further includes a novel low-power display and supports short- and long-range communication. Indoor air quality applications greatly benefit from these three features, since they can easily provide users with data, and also facilitate automated large-scale data acquisition. To fully exploit our platform's unique potential, further software development and optimizations for energy-efficient sensing and wireless communication are necessary.

## ACKNOWLEDGMENTS

This work was supported by the Swiss National Science Foundation under the NCCR Automation project, grant agreement 51NF40_180545, as well as the GFF-IPF Grant of the University of St.Gallen's Basic Research Fund.

## REFERENCES

[1] Jan Beutel et al. 2019. The dual processor platform architecture: demo abstract. In *Procs of IPSN'19.*
[2] Andreas Biri et al. 2020. SociTrack: infrastructure-free interaction tracking through mobile sensor networks. In *Procs of MobiCom'20.*
[3] Robert Falkenberg et al. 2017. PhyNetLab: An IoT-based warehouse testbed. In *Procs of FedCSIS'17.*
[4] Federico Ferrari et al. 2012. Low-power wireless bus. In *Procs of SenSys'12.*
[5] Markus-Philipp Gherman et al. 2021. Compensating Altered Sensitivity of Duty-Cycled MOX Gas Sensors with Machine Learning. In *Procs of SECON'21.*
[6] Andres Gomez. 2020. On-demand communication with the batteryless MiroCard: demo abstract. In *Procs of SenSys'20.*
[7] Neal Jackson et al. 2019. A long-lifetime sensor platform for a reliable internet of things: demo abstract. In *Procs of IPSN'19.*
[8] Matthias Meyer et al. 2019. Event-triggered natural hazard monitoring with convolutional neural networks on the edge. In *Procs of IPSN'19.*
[9] Lukas Sigrist et al. 2020. Harvesting-aware optimal communication scheme for infrastructure-less sensing. *ACM Transactions on Internet of Things* (2020).
[10] Felix Sutton et al. 2015. Bolt: A stateful processor interconnect. In *Procs of SenSys'15.*