Demo Abstract: Light in the Box — Reproducible Lighting Conditions for Solar-Powered Sensor Nodes

Lars Hanschke
Christian Renner
{lars.hanschke,christian.renner}@tuhh.de
Hamburg University of Technology
Research Group smartPORT

Jannick Brockmann, Tobias Hamann, Jannes Peschel, Alexander Schell, Alexander Sowarka
Hamburg University of Technology

ABSTRACT

The restricted energy budget of energy-harvesting sensor nodes demands algorithms for adaptive duty-cycling. However, their comparison and development is hindered by the lack of reproducibility of environmental conditions. We enable replaying recorded light conditions by building an affordable light box. Our self-developed control circuit and high power LEDs allow us to repeatedly replay real environmental illumination data through current and voltage traces. This allows us to directly compare the behavior of nodes running different energy-aware and -predictive algorithms.

CCS CONCEPTS

• **Computer systems organization** → *Embedded and cyber-physical systems*; • **Hardware** → *Sensor devices and platforms*;

KEYWORDS

energy harvesting, solar, cyber-physical systems, test equipment

ACM Reference Format:

Lars Hanschke, Christian Renner, and Jannick Brockmann, Tobias Hamann, Jannes Peschel, Alexander Schell, Alexander Sowarka. 2017. Demo Abstract: Light in the Box — Reproducible Lighting Conditions for Solar-Powered Sensor Nodes. In *Proceedings of SenSys '17*. ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3131672.3136981

1 INTRODUCTION

The deployment of self-sustained devices for cyber-physical systems (CPS) aims at reducing maintenance effort and achieving placement flexibility. However, energy-harvesting devices rely on environmental conditions that experience frequent changes. Forecasting the factors of solar radiation such as clouds, local shadowing and seasonal changes draw attention in research, e.g. in [5] and [1].

Since CPS devices have limited dimensions, their energy resources are restricted. Algorithms adjusting devices' duty cycle, such as [4] or [6], aim at using these resources efficiently. Comparing these algorithms with equal conditions is hardly feasible in practice but is key for advancements in their behavior.

SenSys '17, November 6–8, 2017, Delft, Netherlands

ACM ISBN 978-1-4503-5459-2/17/11…$15.00
https://doi.org/10.1145/3131672.3136981

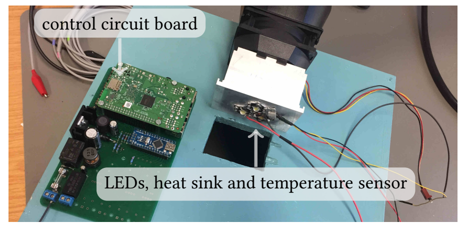

Figure 1: Light box with high power LEDs; full brightness yields 75 mA **at the solar panel with the used harvester.**

We contribute to the development of these algorithms by offering an affordable light box. Our box is able to replay already recorded lighting conditions from the environment through current and voltage traces to enable subsequent testing of energy-aware and -predictive algorithms in the laboratory. We show an extensible structure, offering 75 mA with the prototype harvester from [2], which can be remotely configured and monitored. First, we introduce the goals as well as hard- and software structure of the light box. Second, we show techniques to achieve the accuracy in the range of the harvesting platform.

2 THE BOX

The key idea behind the light box is an accurate yet affordable way of replaying the once recorded solar conditions as seen by the harvester to compare energy-aware algorithms. The harvesting platform we used in [2] recorded solar current and capacitor voltage traces during a long-term test. Traces are fed into the box to replay them accurately multiple times. It is also possible to feed custom traces to evaluate corner cases or performance in situations of special interest.

2.1 Hardware

The control circuit board of our light box hosts four major components: a Raspberry Pi, an Arduino Nano, a DC converter and a LED driver. The Raspberry Pi sends control commands via UART to the Arduino Nano, which generates the PWM signal with adjustable duty cycle to control the LED driver . Two high power LEDs of the Cree MK-R J2 series are served per LED string with forward voltage of 11.7 V at 700 mA. To increase the lighting yield, a reflector is used to steer the beam of the LEDs towards the solar panel. We found, this increases the achievable solar current by up to 25%. To keep the internal temperature of the box at a low level, an efficient heat dissipation from the LED junction is needed. The authors of [3] also

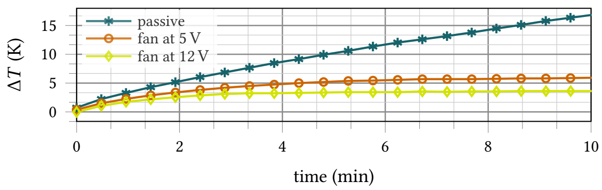

Figure 2: Temperature difference to ambient temperature at heat sink; junction temperature at LED is expected to be 60 K higher; passive cooling insufficient.

found that this influences their repetition accuracy. Our setup uses a conventional CPU heat sink with active cooling. To attach the LEDs to the heat sink, heat conductive tape was insufficient. Since the tape only offers a heat conductivity of 1.4 W/mK, the LEDs quickly started overheating. Replacing this transition by regular thermal paste solved this issue. As displayed in Fig. 2, the temperature difference between heat sink and ambient temperature quickly rises beyond 15 K without active cooling. This is equivalent to a LED junction temperature of 100 °C, which already influences the brightness level and lifetime. We opt for a fan voltage of 5 V, since they are directly available in our circuitry and ensure sufficient cooling. During our tests, we observed temperature differences between box and ambient temperature below 10 K.

With control modules and two LEDs at full brightness, the box consumes 21 W. The total bill of material is around € 110.

2.2 Software

A key requirement of the light box is the remote configurability. The Raspberry Pi hosts a web page with GUI for the light box control. Solar current traces can be uploaded comfortably via web browser in CSV format. Traces are stored in a SQL database for later access. Reliable communication between web GUI and testbed control is ensured via TCP sockets. Before starting an experiment, the box is calibrated. A PWM value is applied and after a calibration time, the Raspberry Pi queries the ADC of the harvester to map the PWM value to solar current.

We use a direct charging circuit for the supercapacitor; thus, the voltage of the capacitor influences the power point of the solar panel and consequently the amount of harvested power. In future, we also plan to ensure compatibility for solar harvesting platforms using MPPT hardware and algorithms. To compensate this issue, we recorded current-voltage-traces at different brightness levels. The solar cell has an open-circuit voltage of 4 V whilst the supercapacitor is rated at a maximum voltage of 2.7 V. Therefore, we are able to fit a linear function into the graph and compensate the difference between capacitor voltage during calibration and voltage during the experiment to increase replaying accuracy.

3 RESULTS AND PRACTICAL MERIT

We depict the benefits of the compensation method in Fig. 3. We compare the overall charge fed into the charging circuit during the replay against the charge of the recorded trace. The same sensor node and harvester is used throughout all experiments. With calibration time of 6 s, the charge difference at the end of the 2.5 h replay

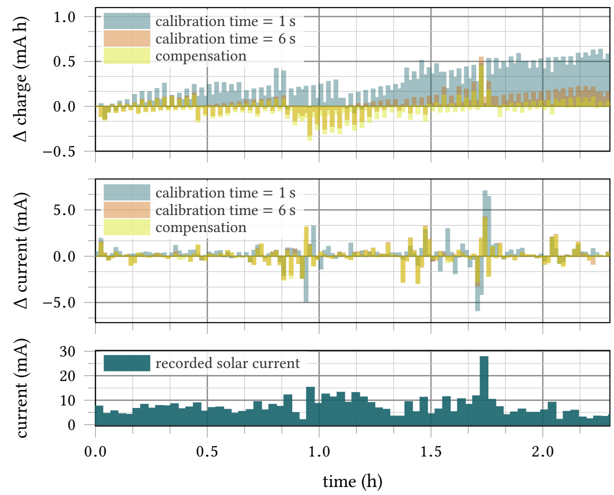

Figure 3: Difference between replayed current trace and observed input at harvester; charge is summed up error during replay; a higher calibration time and compensation of cap voltage difference is needed to increase accuracy.

stays below 0.1 mAh. With a total amount of charge of 17.23 mAh, this results in a relative error of 0.58%. The voltage difference with the used 50 F capacitor is 7.2 mV. With compensation, the voltage difference can be further reduced to 0.72 mV. The practical merit is also shown in the difference to the recorded current traces: the observed trace in mean only differs by 0.62 mA, which is in the range of the measurement accuracy of our 12 bit-ADC with ±2.048 V reference voltage.

This underlines that our box reproduces environmental lighting conditions within the accuracy range of our harvester.

4 CONCLUSION & OUTLOOK

We showed an affordable light box, which is able to reproduce environmental conditions repeatedly in the laboratory. With costs below € 110, we plan to produce more boxes to build a testbed for nodes experiencing different conditions. The box can be easily extended with additional LEDs for larger solar cells or higher light intensity. Additionally, we plan to integrate a mechanism for charging and discharging of the capacitor to enable fully autonomous operation. Follow-up experiments also embrace interacting nodes in multiple boxes and their joint energy budgeting.

REFERENCES

[1] Alessandro Cammarano, Chiara Petrioli, and Dora Spenza. 2012. Pro-Energy: A Novel Energy Prediction Model for Solar and Wind Energy-Harvesting Wireless Sensor Networks. In *MASS*.

[2] Lars Hanschke, Jan Heitmann, and Christian Renner. 2016. Challenges of WiFi-Enabled and Solar-Powered Sensors for Smart Ports . In *ENSsys*.

[3] Josiah Hester, Timothy Scott, and Jacob Sorber. 2014. Ekho: Realistic and Repeatable Experimentation for Tiny Energy-Harvesting Sensors. In *SenSys*.

[4] Clemens Moser, Davide Brunelli, Lothar Thiele, and Luca Benini. 2007. Real-time Scheduling for Energy Harvesting Sensor Nodes. *Real-Time Systems* 37 (2007).

[5] Christian Renner. 2013. Solar Harvest Prediction Supported by Cloud Cover Forecasts. In *ENSsys*.

[6] Christian Renner, Stefan Unterschütz, Volker Turau, and Kay Römer. 2014. Perpetual Data Collection with Energy-Harvesting Sensor Networks. *Transactions on Sensor Networks* 11 (2014).