Indoor Light Scavenging on Smartphones

Denzil Ferreira; Christian Schuss; Chu Luo; Jorge Goncalves; Vassilis Kostakos; Timo Rahkonen
Center for Ubiquitous Computing; Electronics Laboratory
University of Oulu, Finland
{denzil.ferreira;christian.schuss;cluo;jgoncalv;vassilis;timo.rahkonen}@ee.oulu.fi

ABSTRACT

There is a limited amount of scavenging alternatives for smartphones. We assess the feasibility of using indoor light to extend smartphones' battery life. We build a prototype charger that demonstrates that indoor light scavenging is a practical method that can substantially extend battery life on smartphones. The results show that it is feasible and practical to extend battery life with this energy harvesting method. We finally discuss certain obstacles that need to be overcome, especially the redesign of operating systems to account for energy harvesting.

Author Keywords

energy-aware systems; emerging technologies; power management

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION

State-of-art smartphones possess high-performance processors, high-bandwidth network modems, and large-sized displays, which demand increasing power resources. However, over the past decade battery capacity and technology have not kept pace, and in fact manufacturers are favoring product aesthetics at the cost of limiting battery size and capacity. The majority of smartphones today provide at least 24 hours of uptime (*i.e.*, the amount of time the device lasts without recharging), but this varies greatly depending on each unique smartphone use [2]. Similarly, research has shown that users rely on multiple strategies to recharge their devices' battery throughout the day [3]: **Swapping**: carry multiple batteries compatible with their smartphone and exchange the depleted battery for another fully charged; **Packing**: carry an external battery pack that is used to recharge the battery; **Hopping**: carry either a USB cable/power adapter to recharge the battery whenever there is an available socket, over USB or a power outlet; **Scavenging**: carry a solar-panel or piezoelectric generator to recharge the battery. With the exception of scavenging, these strategies require the user to pre-emptively charge an extra battery, or find an available power source. There are two sets of research findings that motivate our focus on scavenging indoor light. Mobile phones are 90% of the time at arms' reach or within the same room [1]. Luminosity traces from 47 participants (2 weeks, Spring) in central Europe suggest that office/daytime hours present the best window to scavenge indoor light [8]. During working hours, users are likely to be in relatively well-lit indoor settings.

EXPERIMENT

Currently, there were no smartphones with a built-in solar-panel available, although there is commercial interest. We investigate indoor light scavenging to extend battery life, testing various indoor light conditions. We use an off-the-shelf Moto G (1st Gen, Android 5.1) smartphone for our experiments and AWARE [5] for instrumenting battery logging. The recorded information includes the current battery percentage, voltage, temperature and a sample timestamp. The battery data is primarily stored locally on the phone and later synced to a remote server before starting a new round of tests, to avoid network usage bias.

For our experiments, we constructed a test chamber (**Figure 1**), which isolates the indoor panel from external light interference. For homogenous light distribution inside the chamber, all the surfaces are bright white. Within the chamber we keep the distance and relative positioning between the solar panel and the light source constant at 30cm and vertically perpendicular. This minimises bias of performance by different angles of the light incidence on the panel surface. On the center of the chamber's ceiling we placed five E27 light bulb sockets. We conducted our experiments with a commonly used indoor light source: 12W 3000K LED light bulbs. Lastly, temperature is known to affect solar cells' performance. We use two temperature sensors (one inside and one outside the chamber) and a ventilation system (*i.e.*, an array of 3 x 80 mm fans controlled by an Arduino Uno microcontroller) to maintain the temperature inside the chamber constant at 21˚C.

Indoor Light Scavenging Prototype

The output power the indoor chargers we constructed ($P_{charger}$) can be estimated as follows:

$$P_{charger} = P_{PV} * \eta_{converter} \qquad \textbf{(Formula 1)}$$

MUM '16, December 12-15, 2016, Rovaniemi, Finland
ACM 978-1-4503-4860-7/16/12.
http://dx.doi.org/10.1145/3012709.3017603

Figure 1. Our controlled environment: external light isolation, at room temperature (≈21˚C) and adjustable light conditions.

where $\eta_{converter}$ is the converter's efficiency percentile. In our experiment the converter used was approximately 70 % efficient. The photovoltaic peak energy (P_{PV}) is a function of three factors:

$$P_{PV} = f(E_v, A_{PV}, m_{PV}) \qquad \textbf{(Formula 2)}$$

E_v is the amount of light, *i.e.*, luminosity (well-lit areas are better, and closer proximity to the source is better); A_{PV} is the area of the panel (bigger is better); and finally, m_{PV} is the solar cell's material power density (varies with the solar cell manufacturer). Our 12" indoor charger is composed of an array of interconnected unitary PV cells, which are scalable and modular ($A_{PV} = 417$ cm^2).

Experimental Results

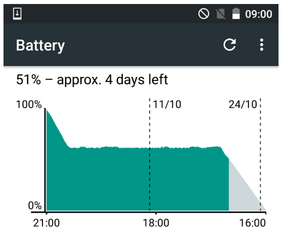
We use the indoor charger (12") via the standard mini-USB port. To deliberately discharge the battery faster and simulate a device in intensive use we used [6] method. The baseline measurement (*i.e.*, when not connected to the indoor charger) is a battery discharging rate (BDR as defined in [3]) of **0.4999% per minute** for the Moto G. Our experimental results are shown in Table 1.

# Lamps	Light intensity (lx)	BDR (%/min)
1	3,460	0.5159
2	6,800	0.5072
3	10,490	0.4906
4	13,980	0.4823
5	17,810	0.4674

Table 1. Results per light condition and discharging rate in % per minute (i.e., lower is better). Green highlights successful discharge slowdown.

DISCUSSION AND CONCLUSION

We are unable to actually charge the test phone. We can however, slow down the discharge. To further investigate why, we measure the current on the device while idle and when charging. To our surprise, we found that whilst connected to the charger, our device actually consumed more battery than when not charging. While not charging and idle, the device power consumption is 7.67 mA (29.15 mW). If connected to the AC power socket, this value increases to 27.38 mA (217.8 mW). In other words, in theory, we must produce more than 217.8 mW in power to sustain the phone indefinitely alive, and above this threshold the phone will actually increase its charge. We further tested our panel with additional devices (*e.g.*, Samsung S6 Edge, Galaxy S2 mini, Nexus 5) and observed the same behavior: they consume more power while in a charging state than when idly discharging. We could only keep them indefinitely alive if we disabled the Wi-Fi, removed the SIM card and kept the screen OFF (**Figure 4**).



51% – approx. 4 days left

Figure 2. Nexus 5 alive indefinitely (idle on an office desk (≈ 5960 lx), WI-FI OFF, no SIM card, screen OFF (12" poly-Si).

If **idle**, on average, the phone consumes about 30 mW. The solar charger can provide this power with our 12" charger and as little as 500 lx. However, the phone does not stay in idle when we connect the indoor charger. If **charging**, on average, the phone consumes about 200 mW. The indoor charger with a solar panel of 12" diagonal needs a much stronger light source to reach that output (charging) power (>10,500 lx, by reducing the distance to the light source). Alternatively, we could use a larger charger (> 80" diagonal) in order to keep the same low luminosity (not ideal to carry!).

The challenge is whether asking users to become conscious of where they place their smartphone to maximise indoor charging (close to light source and well-lit area) is a significant and somewhat disruptive change to our human-battery interaction habits [4]. It is more convenient to recharge the device on the power socket overnight, every day, than constantly worry about where the device is located. However, given that many hours of modern daily routines are spent indoors, a solar-charging smartphone case could extend their smartphones battery life. If left unattended and under a good source of light, charging may be possible. For this reason, a valuable research avenue is to investigate nudging techniques to inform and train users on how to place their phone to increase charging performance.

ACKNOWLEDGMENTS

This work is partially funded by the Academy of Finland (Grants 276786-AWARE, 285062-iCYCLE, 286386-CPDSS, 285459-iSCIENCE), and the European Commission (Grants PCIG11-GA-2012-322138, 645706-GRAGE, 6AIKA-A71143-AKAI).

REFERENCES

1. Dey, A.K., Wac, K., Ferreira, D., Tassini, K., et al. Getting closer: an empirical investigation of the proximity of user to their smart phones. In *International Conference on Ubiquitous Computing.* ACM, 2011, 163-172.
2. Ferreira, D., Dey, A.K. and Kostakos, V. Understanding human-smartphone concerns: a study of battery life. In *International Conference on Pervasive Computing.* Springer-Verlag, Berlin, Heidelberg, 2011, 19-33.
3. Ferreira, D., Ferreira, E., Goncalves, J., Kostakos, V. and Dey, A.K. Revisiting Human-Battery Interaction with an Interactive Battery Interface. In *International Joint Conference on Pervasive and Ubiquitous Computing.* ACM, 2013, 563-572.
4. Ferreira, D., Goncalves, J., Kostakos, V., Barkhuus, L. and Dey, A.K. Contextual Experience Sampling of Mobile Application Micro-Usage. In *International Conference on Human-Computer Interaction with Mobile Devices and Services.* ACM, 2014, 91-100.
5. Ferreira, D., Kostakos, V. and Dey, A.K. AWARE: mobile context instrumentation framework. *Frontiers in ICT 2,* 6 (2015), 1-9.
6. Hosio, S., Ferreira, D., Goncalves, J., van Berkel, N., et al. Monetary Assessment of Battery Life on Smartphones. In *Conference on Human Factors in Computing Systems.* ACM, 2016, 1869-1880.
7. Schuss, C., Eichberger, B. and Rahkonen, T. Design specifications and guidelines for efficient solar chargers of mobile phones. In *Multi-Conference on Systems, Signals & Devices (SSD).* IEEE, 2014, 1-5.
8. Van den Broucke, K., Ferreira, D., Goncalves, J., Kostakos, V. and De Moor, K. Mobile Cloud Storage: A Contextual Experience. In *International Conference on Human-Computer Interaction with Mobile Devices and Services.* ACM, 2014, 101-110.