PhD Forum Abstract: Advancing Solar Cells: Beyond Energy Harvesting to Positioning and Communication

Yanxiang Wang
yanxiang.wang@unsw.edu.au
University of New South Wales and CSIRO
Australia

ABSTRACT

Extensively studied for energy harvesting, solar cells present a sustainable and renewable solution for producing Internet of Things (IoT) devices that operate autonomously without the need for battery replacement. Our goal is to augment solar cells with positioning and communication capabilities, aiming to further diminish the size, weight, power consumption, and cost of IoT products. This approach leverages the photocurrent signals generated by solar cells, which are influenced by various factors, including the angle of light incidence, light intensity, and environmental reflections—attributes that can vary with location. Furthermore, by modulating the light source, we can alter the solar photocurrent, enabling the reception of data. This research explores the capability of solar cells to discern light spectral information, offering a nuanced response to illumination. This enhanced sensitivity has the potential to significantly improve localization precision and communication effectiveness.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing**.

KEYWORDS

Indoor Localization, Solar Cells, Spectral Information, Visible Light Communication

1 INTRODUCTION

As populations increase, the demand for energy becomes more strained. Solar energy is a green energy source that produces no pollution to the environment, in contrast to fossil fuels such as coal, oil, and minerals. Photo-voltaic (PV) devices can generate electricity from sunlight and have been applied in various fields, including powering houses and intelligent street lighting. With the development of the Internet of Things, the number of electrical devices has grown significantly, and most use batteries as power sources due to their physical size and convenience. However, recharging batteries is time-consuming, and [?] have attempted to use solar cells as the primary energy source to extend device life. Additionally, solar cells mounted on moving objects, such as a walking person, generate photo-current signals that contain distinct patterns caused by motion. Researchers have utilized solar cells to recognize simple hand gestures and human activities using similar principles. However, unlike conventional movement sensors such as inertial measurement units (IMUs), which can record physical status including acceleration and angular velocity, the relationship between photo-current signals and contextual information is complex. This is because the photo-current signals are affected by factors such as incident angle, light intensity, light spectrum, and reflection. Further more, the contextual information behind the physical characteristics can be used for positioning and communication scenarios where solar cells work as sensors and receivers.

2 LIGHT SPECTRAL INFORMATION

As solar cells become increasingly integrated into IoT systems, their widespread deployment in indoor environments is anticipated. Building upon this premise, we investigate the potential of constructing an positioning and communication system utilizing solar cells. However, rather than simply employing solar cells as substitutes for photo-diodes, our research delves into the advantages that spectral information can bring to the system. We aim to extract this spectral information from solar cells, thereby endowing the system with advanced sensing capabilities that surpass mere intensity measurements.

Currently, there are three main types of light bulbs available in the market: incandescent light bulbs (ICL), compact fluorescent lights (CFL), and light-emitting diodes (LEDs). Each type of bulb emits light with a unique spectral power distribution (SPD) due to their different emission processes. These distinct emission mechanisms lead to varying SPD patterns for each type of bulb, as shown in Figure 1. The Light Spectrum Database [1] records spectrum data for 311 models of light bulbs, showcasing their unique SPDs.

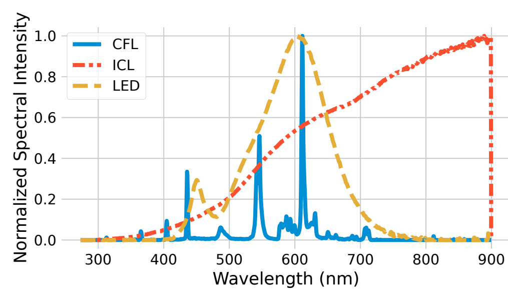

Figure 1: The SPDs of different light bulb types.

Besides light from light sources, light is also reflected by objects in the environment. Moreover, the reflected light shows variations because of different materials, textures, and colors. To measure the object's reflection selectivity for different wavelength light, here, reflectance is used to show the materials' reflection features, which can be formulated as $R_\lambda = L^r_\lambda / L^i_\lambda$, where R is the reflectance in wavelength λ, L^r and L^i are the spectral radiance of reflected light and incident light, respectively. The reflectance varies depending on the kind of materials and colors. For instance, the red interior wall has higher reflectance values for the red light range (622 - 780 nm) but lower ratios in the rest wavelength range. This disparity suggests that certain objects would selectively absorb particular

979-8-3503-6201-5/24/$31.00 ©2024 IEEE
DOI 10.1109/IPSN61024.2024.00060

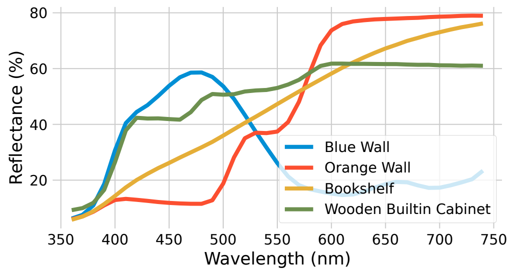

Figure 2: The reflectance of different materials.

light wavelengths, resulting in variations in the wavelengths of reflected light. This is the basis for how different colors are seen by the human eye and cameras. There are 1,294 different types of opaque materials' reflectance data measured with a spectrometer in [3]. For instance, four materials' reflectance curves are presented in Fig. 2, showing distinct reflection characters.

Since most indoor environments have lighting infrastructure in nature, there is an increasing interest in using light for indoor localization. When compared to radio, light is more stable and has a significantly higher deployment density than WiFi. The majority of existing light-based localization systems, on the other hand, focus on changing the LED such that the lighting infrastructure could provide valuable beacons or spatial information to receivers for localization [5, 8].

Different to the existing works that control the light sources, we propose to use light spectral distribution, i.e., the intensity of light at distinct wavelengths within the visible spectrum, to identify a specific place. The idea is that different locations are surrounded by different environmental objects, such as walls with different colors, doors with different materials, and so on, which have different light reflection properties. We have proved that the spectrum information of light not only can be used for indoor localization but also performs better than intensity data [2, 7].

3 SOLAR CELLS FOR POSITIONING

However, compared to specifically designed sensors used in [2, 7], significant reconstruction costs could be reduced if we can obtain spectral information using existing solar cell installations. To this purpose, we propose to utilize readings from multiple solar cells that are made by various materials, including silicon, organic, amorphous, and etc. Different materials exhibit nonidentical absorption response at different wavelength [6]. The reason is that different materials have different band gap energies, which determine the wavelengths of light that can be absorbed by the material. By choosing the appropriate materials, solar cells can be designed to have different spectral responses, making them more efficient and effective for indoor localization applications.

4 SOLAR CELLS FOR COMMUNICATION

Apart from using the spectral information for positioning, it can also benefit the visible light communication (VLC). We aim to use solar cells as receivers for VLC. Using solar cells as receivers for VLC based on their spectral response offers several advantages. First, it eliminates the need for specialized receivers, which can be expensive and difficult to obtain. Solar cells are widely available and can be easily integrated into electronic devices. Second, it allows for the use of a wider range of wavelengths, enabling the transmission of more data at higher speeds. Third, it offers improved energy efficiency, as the solar cell receiver can simultaneously harvest energy from the transmitted light while detecting the data signal. Specifically, we propose to apply the Color Shift Key (CSK) modulation scheme. The system will consist of a light source that transmits data and solar cells that receive the signals and convert them into electrical signals. The key challenge is extracting the spectral information from solar cell readings.

5 HARVESTING VS SIGNAL ACQUISITION

In solar cells, balancing energy harvesting efficiency with signal acquisition quality involves two primary strategies: time slots and power splitting [4]. Time slots alternate the solar cell's function between generating electrical energy and acquiring light signals at different intervals. Power splitting divides the generated photocurrent into AC (for sensing light) and DC (for charging) branches, allowing simultaneous operation but at the cost of reduced signal amplitudes, potentially impacting acquisition. Unlike the time-slot approach, which limits the solar cell to a single function at any moment, power splitting enables dual functionality but with a trade-off in performance. Optimizing this balance between energy harvesting and signal acquisition represents a key focus of the PhD thesis.

6 ABOUT ME AND ACKNOWLEDGEMENT

Yanxiang Wang started the PhD journey on June 2021, and expects to finish the thesis before May 2025. He would like to thank Prof. Wen Hu and Prof. Mahbub Hassan for their help in revising the manuscript. This work was partly supported by the Australian Research Council Discovery Project DP210100904, UNSW Scientia PhD Scholarship Scheme and CSIRO Data61 PhD Scholarship Program.

REFERENCES

[1] Lamp Spectral Power Distribution Database. 2022. LED EnergySmart BR30 Domestic. https://lspdd.org/app/en/lamps/2492.

[2] Jiawei Hu, Yanxiang Wang, Hong Jia, Wen Hu, Mahbub Hassan, Ashraf Uddin, Brano Kusy, and Moustafa Youssef. 2022. Passive light spectral indoor localization. In *Proceedings of the 28th Annual International Conference on Mobile Computing And Networking*. 832–834.

[3] J Alstan Jakubiec. 2016. Building a database of opaque materials for lighting simulation. In *PLEA 2016–Cities, Buildings, People: Towards Regenerative Environments, Proceedings of the 32nd International Conference on Passive and Low Energy Architecture*.

[4] Meiwei Kong, Chun Hong Kang, Omar Alkhazragi, Xiaobin Sun, Yujian Guo, Mohammed Sait, Jorge A Holguin-Lerma, Tien Khee Ng, and Boon S Ooi. 2020. Survey of energy-autonomous solar cell receivers for satellite–air–ground–ocean optical wireless communication. *Progress in Quantum Electronics* 74 (2020), 100300.

[5] Ye-Sheng Kuo, Pat Pannuto, Ko-Jen Hsiao, and Prabal Dutta. 2014. Luxapose: Indoor positioning with mobile phones and visible light. In *Proceedings of the 20th annual international conference on Mobile computing and networking*. 447–458.

[6] Yoshinori Umetsu, Yugo Nakamura, Yutaka Arakawa, Manato Fujimoto, and Hirohiko Suwa. 2019. Ehaas: Energy harvesters as a sensor for place recognition on wearables. In *2019 IEEE International Conference on Pervasive Computing and Communications (PerCom)*. IEEE, 1–10.

[7] Yanxiang Wang, Jiawei Hu, Hong Jia, Wen Hu, Mahbub Hassan, Ashraf Uddin, Brano Kusy, and Moustafa Youssef. 2023. Spectral-Loc: Indoor Localization using Light Spectral Information. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 7, 1 (2023), 1–26.

[8] Bo Xie, Guang Tan, and Tian He. 2015. Spinlight: A high accuracy and robust light positioning system for indoor applications. In *Proceedings of the 13th ACM Conference on Embedded Networked Sensor Systems*. 211–223.