Demo: Backscatter-enabled Polymorphic Light Sensors

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ABSTRACT

Light as a medium for sensing and communication enables new scenarios, such as controlling devices with gestures, or communication for Internet of Things (IoT) devices. However, a limitation of existing systems is that they often sense only a narrow part of the light spectrum. We argue that the ability to sense a broad light spectrum significantly enhances ability of such systems expanding possible application scenarios. We demonstrate our work in progress to develop the concept of polymorphic light sensing (PLS). PLS sensor morphs itself according to applications requirements, to track desired parts of the light spectrum (colours, infrared, and ultraviolet light). We couple the PLS sensor with ultra-low power backscatter mechanism, and demonstrate this enables us to sense and communicate the broad spectrum, while operating battery-free.

KEYWORDS

Light sensing; Polymorphic sensing; Backscatter

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1 INTRODUCTION

Light enables application scenarios such as gesture recognition [4, 9], communication [7], and health care [6]. As a result, the past years have seen a significant interest to develop light sensing systems. The light spectrum can be broadly segmented based on wavelengths to form regions such as ultraviolet, visible and infrared light. In particular, the visible light region can be split into various colours which play a distinct role in our lives. For instance, tracking of light components is essential in health care applications; blue light emitted from devices such as smart phones or computers can negatively impact sleep rhythms [6]. Furthermore, a high level of exposure to ultraviolet radiation can cause skin cancer [5]. In another example, supporting the ability to track the intensity of particular colors has the potential to benefit the detection of overall human behaviour such as complex hand gestures. Thus, in this demonstration, we argue that to support diverse applications, or enhance existing application scenarios, it is important to support the ability to sense the components of the entire light spectrum.

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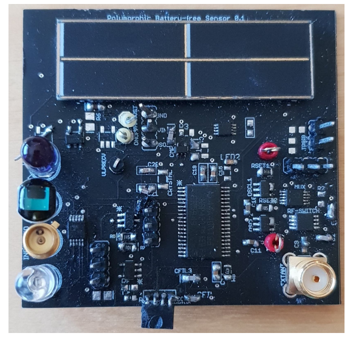

Figure 1: *Battery-free polymorphic light sensor.* We can sense ultraviolet, infrared, blue and visible light, and communicate them using a backscatter mechanism. We can operate solely on harvested energy, which is obtained using a small sub-credit card-sized solar cell and stored in a capacitor.

However, most existing light sensing systems are often energy-expensive in the sense that they employ power-hungry mechanisms to sense and to communicate. Hence, these systems are forced to operate on batteries or through external power, which negatively impacts the sustainability of deployment. Specifically, photodiodes are coupled with energy-expensive transimpedance amplifiers (TIAs) and can only sense narrow parts of the light spectrum. This is contrary to our goal of sensing the full range of the light spectrum. Moreover, coupling of the photodiodes using existing light sensing designs might require combinations of several amplifiers which may prohibitively increase the power consumption.

We demonstrate our work in progress [8] to design a polymorphic light sensor (PLS) that can sense the broad light spectrum and communicate sensor information wirelessly through very-low power backscatter communication [10]. Our PLS has the capability to fully operate on energy harvested from ambient light. We show the hardware prototype in the Figure 1. In the following sections, we describe the challenges we encounter in the design of our PLS.

2 POLYMORPHIC LIGHT SENSING

Many state-of-the-art light sensing systems [2, 7, 11] only track a small subset of the light spectrum which limits the applicability of these designs in various scenarios. This constraint arises from use of a single photodiode that operates within a narrow light spectrum, which is then coupled together with an energy expensive TIA. We overcome this constraint, by introducing the PLS. The PLS adapts to the application requirements and can track infrared, UV, blue and visible light, thus demonstrating a polymorphic behaviour.

We design the polymorphic light sensing mechanism by fusing photodiodes and LEDs which are sensitive to different parts of the light spectrum. We achieve this functionality by using a multiplexer chip to select between light sensors. To improve the energy-efficiency of the design, we operate the photodiodes in photovoltaic mode, which allows us to avoid the energy expensive TIA.

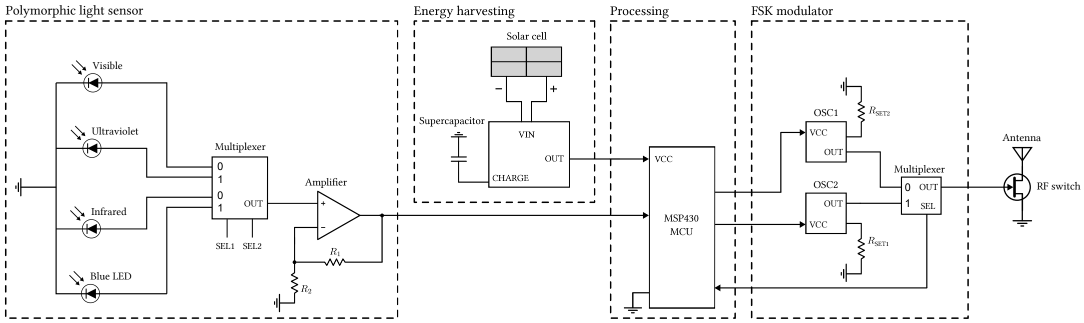

Figure 2: *Battery-free Polymorphic Light Sensor.* Combining photodiodes and LEDs with sensitivity to different parts of the light spectrum enables us to sense broad light spectrum. Operation in photo-voltaic mode enables operation on the harvested energy. Light sensor readings are communicated using ultra-low power backscatter communication built using LoRea.

Instead, we use a low-power voltage amplifier. The fusion mechanism we design using the multiplexer allows us to use the same amplifier for all photodiodes. This helps with reusing components to improve the energy-efficiency.

Implementation. Figure 2 demonstrates the PLS mechanism. To sense the blue color, we use LEDs [1]. While to sense infrared, visible or ultraviolet – light, we employ photodiodes which operate within these regions. We fuse LEDs and photodiodes using an ultra-low power multiplexer chip (Analog Devices ADG704). Next, the signal is amplified using an low power amplifier (ST Microelectronics TSV630). The fusion mechanism is sufficiently low-power to support operation on energy harvested from small solar cell.

3 ENERGY HARVESTING, PROCESSING AND COMMUNICATION

To operate battery-free, we harvest energy from a small sub credit card sized solar cell. We couple the solar cell to a energy harvester chip, which manages and stores the harvested energy onto a small super capacitor of size 10 mF. The harvested energy is used to enable the operation of the circuit without requiring batteries.

Light readings from polymorphic sensor needs to be digitised, processed and communicated to a powerful device for further processing, as is commonly done in state-of-the-art systems [2–4, 9]. We use a low-power microcontroller to perform digitisation and local processing of the light sensor readings. To conserve energy, we commonly operate the microcontroller in the low power modes.

At the last step, the processed light readings, are communicated using energy efficient backscatter mechanism. We build on the design of the backscatter tag presented by LoRea [10]. This allows us to support wireless transmission of light sensor readings to a large distance (kilometers) while consuming a peak power of 70 µWs. We show the schematic of the module in the Figure 2.

Implementation. The backscatter module is designed using very low power oscillators LTC6906 and multiplexer ADG 704, and RF switch HMC190BMS8. We implement the processing block using state-of-the-art low-power microcontroller from Texas Instruments MSP430. As a solar cell we use thin film solar cell from Powerfilm for energy harvesting, and BQ 25570 as an energy harvester.

4 DEMONSTRATION

In this demonstration, we will present the operation of the polymorphic light sensor. We demonstrate that it enables us to track and communicate various components of the light spectrum. We also demonstrate that this functionality allows us to improve the ability of hand gesture recognition under unmodulated light. Furthermore, we show that the system can harvest energy under diverse ambient light conditions. For this demonstration, we need a table, monitor, power outlets, and a table lamp.

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