Position: Wearable Polymorphic Light Sensors

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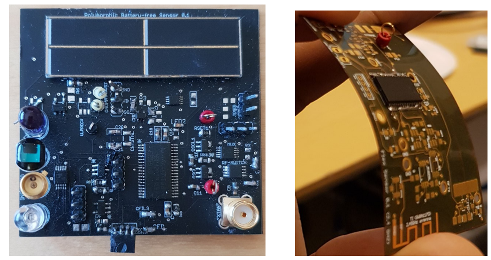
1 INTRODUCTION

Light is an emerging medium to enable sensing applications. Past years have seen a sustained effort to develop light sensing systems. Some efforts demonstrate the ability to detect gestures by sensing cast shadow [1, 2]; other systems use light to support communication [5]. While these systems demonstrate new capabilities, all of them utilize only a small part of the spectrum for their operation.

Light can be broadly divided based on the wavelength into components such as ultraviolet, visible and the infrared light. Each of them plays a distinct role in our life: visible light helps us perceive the environment, on the other hand, infrared and ultraviolet light is invisible to human eyes, which makes them appealing to enable communication or sensing without causing a disturbance. The visible light itself could be split into different colours which have a disparate impact on humans. As an example, the blue light emitted from mobile devices can negatively impact sleep rhythms.

In this position paper, we argue that the ability to sense the broad light spectrum is an important capability which is lacking in the design of existing light sensing systems. We develop this important capability and call it polymorphic light sensing (PLS). PLS mechanism enables tracking of different light components such as infrared, ultraviolet, visible light and different colours. Such a capability enables several wearable application scenarios that are not possible with existing designs. As an example, we imagine that such capability could enable wearable devices that could help monitor exposure to harmful light radiations such as ultraviolet or blue light. Such sensors could with the help of flexible electronics be worn on clothes, as we show in the Figure 1. In another application scenario, the ability to sense different colours could help to improve the ability of hand gesture sensing systems [6].

While sensing a broad light spectrum is an important capability, which we support with PLS. Existing light sensing designs are also restricted due to the energy expensive nature, and lack of wireless



(a) Prototype (b) Flexible variant

Figure 1: Wearable Polymorphic Light Sensors *It enables persistent monitoring of the exposure to ultraviolet, infrared, visible and blue light. The system can operate without batteries, and the readings communicated through backscatter mechanism. Flexible form factor can enable these sensors to become part of the clothing.*

transmission capability. A high power consumption requires sensors to be externally powered, through cables or bulky batteries, restricting application scenarios particularly for wearable applications that often operate on small batteries or energy harvested from the environment. To overcome this challenge, we optimize the PLS for low power consumption, achieving light sensing within 100 µWs. Further, to support wireless transmissions of light sensor readings, we build on LoRea [7], and use backscatter transmissions to offload light sensor readings. This enables light sensing operation even on energy harvested from small sub credit card sized solar cell, or thin film batteries.

At a high level, our system works as follows: we sense different parts of the light spectrum and communicate these to a powerful device such as a smartphone. The system performs this task through a series of step. First, it harvests energy from the ambient light using a small solar cell and stored onto a supercapacitor. As continuous operation on harvested energy is challenging due to dynamics of light under mobility [8], we design a low-power mechanism to switch between battery and supercapacitor. Finally, the sensed light readings are communicated to the user through a backscatter mechanism designed using LoRea [7].

Through the design presented in this position paper, we present the design of the first wearable light sensing system that can sense and wirelessly communicate the broad light spectrum while being able to operate battery-free. Recently, a commercial light sensor was introduced to monitor exposure to UV levels [3]. The sensor is similar to our effort; however, unlike our system, this sensed and communicated only one component (UV) and communicated through short-range NFC transmissions.

2 POLYMORPHIC LIGHT SENSING

The constraint that existing light sensing systems [1, 4, 8] track only a subset of the light spectrum arises from these systems using a single photodiode/solar cell, which often operates within a narrow

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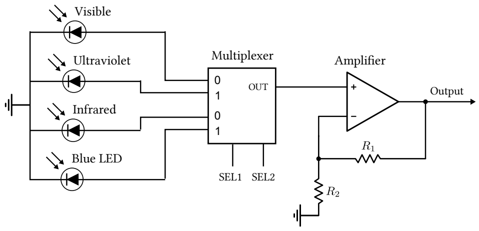

Figure 2: *Polymorphic Light Sensing mechanism.* *Combining photodiodes, LEDs and solarcells using ultra-low power multiplexer enables us to sense broad light spectrum.*

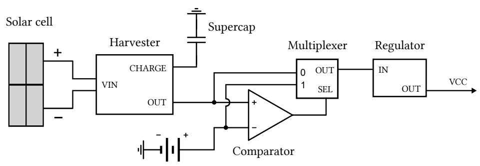

Figure 3: *Switchover mechanism.* *In poor energy harvesting conditions, we automatically switch to a battery for operation. The mechanism uses only two components, and consumes a peak power of few* µW*s. We regulate the output to ensure a constant voltage.*

light spectrum. To overcome this constraint, we introduce a new sensing capability that we call, polymorphic light sensing (PLS). This enables the application to adapt to the requirements, i.e., if an application requires sensing of infrared or UV light, the mechanism adjusts and supports sensing of these components.

We design the PLS mechanism by combining photodiodes and LEDs with sensitivity to different parts of the spectrum using a multiplexer. A disadvantage of using a multiplexer is that it allows us to select only one sensor at a time, i.e., we have to read photodiodes sequentially. This, however, is not a challenge for our application, as we can select the photodiodes within a few µs, which is sufficient for our target application scenarios. To sense the blue colour, we use LEDs. While to detect infrared, visible or ultraviolet – light, we employ photodiodes which operate within these regions. To support operation on harvested energy for some of our target application scenarios, we design the mechanism to be energy efficient. We achieve this by enabling the sharing of the energy expensive amplifier, and also operate the photodiodes in photovoltaic mode, which allows us to avoid energy expensive transimpedance amplifier, and instead use a low-power amplifier.

Figure 2 demonstrates the mechanism. We fuse LEDs and photodiodes using an ultra-low power multiplexer chip (Analog Devices ADG704). Next, the signal from the amplifier is amplified using an ultra-low power amplifier (ST Microelectronics TSV630). The fusion mechanism consume only few µW for its operation, while the voltage amplifier consumes < 100 µW of power for its operation.

3 POWER MANAGEMENT

Visible light links are dynamic and can experience rapid changes in the light intensity levels [8]. These changes can be due to natural variations in the light levels, or due to the mobility of the user, as would be commonly encountered in a wearable application. Figure 4 illustrates change encountered in the signal level obtained from a solar cell under mobility conditions that a wearable application might meet. Such extreme changes in the signal received from a

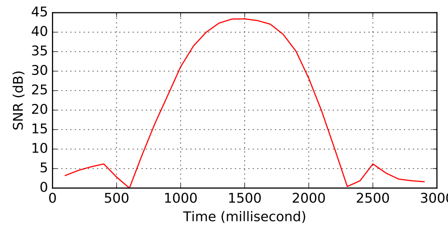

Figure 4: Change in signal-to-noise (SNR) ratio under mobility conditions encountered by wearables. *Mobility induces rapid changes in signal levels impacting the energy harvesting ability.*

solar cell, makes it challenging for energy harvesting systems, as the energy available to harvest becomes unpredictable. Further, in low-light conditions, the amount of energy available to harvest from small solar cells might also not be sufficient. Hence, to tackle this challenge, we propose to combine a small battery with the supercapacitor. This ensures that we switch to battery for operation when sufficient energy is not available to harvest. In our present prototype, we do not charge the internal battery, and it needs to be replaced when exhausted. In future, we plan to overcome this limitation and support charging of the internal battery.

We design this mechanism using ultra-low power comparator (TS881) and a multiplexer (ADG 702), as we show in the Figure 3. The comparator continuously compares the output from the harvester, and the battery, and automatically switches to the battery under poor harvesting condition. This switchover mechanism consumes only a few µWs of power for its operation.

4 WIRELESS COMMUNICATION

Light readings are communicated wirelessly in the final stages. To support transmissions at low power consumption, we use backscatter communication. A backscatter radio communicates by reflecting or absorbing the ambient wireless signal. This operation can be performed at few µWs of power consumption, representing orders of magnitude improvement over conventional radio transceivers. To generate a carrier signal, we build on LoRea [7] which demonstrates the ability to generate carrier signal from commodity radio. Next, we transmit readings building on LoRea [7]. This allows us to transmit light readings at a peak power of 650 µWs, which can be supported on energy harvested.

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