Poster: Insights into RGB-LED to Smartphone Communication

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Abstract

We present our efforts to design a communication system between an ordinary RGB light emitting diode and a smartphone. This work in progress presents our preliminary findings obtained investigating this poorly known and unusual channel. We give engineering insights on driving an RGB light emitting diode for camera communication and discuss remaining challenges. Finally, we propose possible solutions to cope with these issues that are blockers for a user ready implementation.

1 Introduction

In the past decade, the interest in visible light communication (VLC) has rapidly grown in the research community, opening the door to novel usages and commercial applications. A particularly interesting field of VLC is the Optical Camera Communication (OCC) that provides a ubiquitous communication link between any light emitting diode (LED) and users through their smartphone camera.

With the fast smartphone market expansion, LED-to-smartphone communication opens the door to many commercial applications e.g. indoor localization, contextual information broadcast or interaction with IoT devices like smart toys. Consequently, since the seminal work by *Danakis et al.* [2], researchers have proposed numerous solutions to bring LED-to-Camera communication to the industry. Nevertheless, most of them study white ceiling LEDs or small monochrome LEDs [3], but RGB LEDs have been forsaken.

As a continuation of our IoT device to smartphone communication system [3], we propose to increase the channel capacity by replacing the low power 5mm monochrome LED with the equivalent RGB LED. In fact, RGB LEDs are often preferred to monochrome LEDs in commercial electronics since their color can be changed at runtime. We applied the methods found in the literature for power ceiling RGB LED to smartphone communication [1, 4, 6] and we faced unexpected behaviors due to the weak power and the difference in the LED size, making these standard solutions unusable in our system at this point.

After some investigations, we share in this paper our first findings, discuss the remaining challenges and propose candidate solutions we expect to ease the decoding process.

2 RGB LED as emitter

An RGB LED is composed in fact of three LEDs: red, green, and blue, inside one package. Typically an RGB LED has four pins: one common pin that is connected to ground and one for each of the three LEDs. This allows a program to vary both the color and the color intensity level of the RGB LED.

Modulation Schemes: while On-Off keying (OOK) combined with the Manchester line code is usual for monochrome LEDs [2, 3], Wavelength Division Multiplexing (WDM) and Color-Shift-Keying (CSK) have been proposed for RGB LEDs respectively by *Liang et al.* [5] and by *Chen et al.* [1]. WDM schemes modulate the three color channels[1] independently with distinct input data. On the contrary, in the CSK scheme, the transmitted bits match specific color coordinates in the color space.

Achievable Color and Frequency: we experimentally found the color we can obtain with our low-cost hardware to establish a suitable modulation scheme and we defined a constellation of symbols.

3 Identifying Challenges

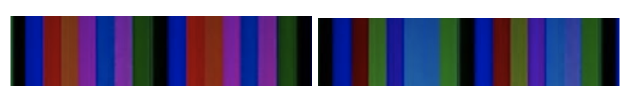

Figure 1. The same symbols observed with different ISO and white balance camera settings.

1) Limited number of symbols that the RGB LED can produce: the RGB LED can produce only a few colors. Some of these symbols seem to be very close and so, are often difficult to distinguish. The experiments bring out that

[1] In this paper, *color* and *channel* are synonyms.

Figure 2. The same 8-CSK symbols sent consecutively and repetitively are perceived differently in the picture.

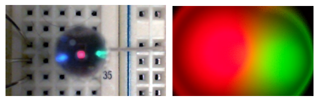

Figure 3. The RGB LED without modulation. On the left, the LED is strongly dimmed with the 3 channels ON. On the right, the LED is normally dimmed with only the red and green channel ON.

the green channel state is not easily determinable for the symbols for which the green is mixed with another color.

2) Color diversity across devices, camera settings and ambient light: various smartphones will render the colors differently and that behavior also happens on the same device when the ambient lighting conditions change or by modifying the ISO, exposure and white balance settings. Fig 1 shows the color rendered when changing the ISO setting of the camera.

3) Intra-frame color diversity: this phenomenon is shown in Fig.2, where the symbols are completely disparate across the regions considered in the picture.

4) Color mixing issue with the cheap low-power RGB LEDs: as shown in Fig. 3, even without modulation and with proper use of the RGB LED, the colors are not perfectly mixed so that two or three color beams are visible. However, to exploit the rolling shutter effect, we expect that the color remains the same along a row of pixels when the LED is not modulated.

5) Real-time implementation: color detection requires complex computer vision algorithms that need a three-dimensional matrix as input. That is three times larger than the one for a monochrome LED. Previous works [4, 1, 6] all present a compute-intensive demodulation method using Matlab or OpenCV on a computer. A real-time algorithm implementation on a smartphone has not been unveiled yet.

4 Solutions Proposal

We are proposing and currently testing a few methods to overcome the issues we have presented in Sec. 3.

Demodulation methods: a demodulation method within the LAB color space would be preferred, as only two vectors

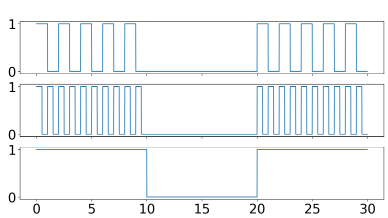

Figure 4. On the bottom, the red channel input with the regular f_{csk} CSK modulation. Above, the CSK modulation is combined with a $fpwm$ PWM and $f_{pwm}/2$ PWM so that dark and light stripes will appear within the CSK symbol period.

Figure 5. The 8-CSK modulation symbols combined with a 20 kHz PWM on the green channel only.

(A and B) describe the chromaticity, instead of all the three for the RGB color space. Because the computer vision algorithms are particularly adapted to the GPU architecture, using the smartphone GPU can considerably fasten the demodulation process compared to a CPU implementation. This can be done using *Renderscript* framework on Android, and the *Apple Metal 2* framework on iOS.

Use the Pulse Width Modulation (PWM): by modulating a PWM output, configured with a frequency f_{pwm}, higher than the CSK frequency f_{csk}, but below the CMOS sensor sampling frequency, we can induce stripes more or less spaced within a CSK symbol. That method may extend the range of symbols as it is shown in Fig. 4.

Constellation choice: we propose to use a combination of M-CSK and N-PWM modulation schemes. Samples of symbols are shown in Fig 5. Based on the observations in Sec. 2, we found that the N PWM frequencies f_{pwm}^i must be $16 \leq f_{pwm}^i \leq 22$ kHz to comply with the camera shutter bandwidth. To avoid inter-symbol interference (ISI), i.e. to be able to determine the difference on the stripes spacing, two adjacent PWM frequencies f_{pwm}^i and f_{pwm}^{i+1} must be spaced with $\Delta_f \geq 2kHz$.

Thus, each channel has 6 states, e.g. for the green channel: $G_{f_{pwm}^1}$, $G_{f_{pwm}^2}$, $G_{f_{pwm}^3}$, $G_{f_{pwm}^4}$, G_{ON}, G_{OFF} with $f_{pwm}^i = \{16, 18, 20, 22\}$ kHz, $i = 1, \ldots, 4$. However, we make the hypothesis that choosing symbols where f_{pwm} varies in many channels will cause unmanageable ISI.

Furthermore, using the PWM modulation on only the green channel will help the color identification process so that the green channel state can be inferred from the presence of stripes.

5 Conclusion

In this work, we point out through a series of experiments the challenges of RGB LED to camera communication. We proposed several ideas that we expect to ease the decoding process. These algorithms and methods are under development and implementation. In a future work, we will conduct and extensive experimentation campaign to evaluate and (in)validate the hypothesis presented in this work.

6 References

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