International Journal of Advanced Smart Convergence Vol.4 No.2 94-102 (2015)
http://dx.doi.org/10.7236/IJASC.2015.4.2.94

IJASC 15-2-14

Forward Error Correction based Adaptive data frame format for Optical camera communication

Quoc Huy Nguyen[*], Hyung-O Kim[*], Minwoo Lee[*], Juphil Cho[**], Seonhee Lee[***†]

[*]*Graduate School of NID Fusion Tech., Seoul National Univ., of Science and Tech., Seoul, Korea*
[**]*Dept. Of Integrated IT & Communication Eng., Kunsan National Univ., Kunsan, Korea*
[***]*Dept. Of Electronic & IT Media Eng., Seoul National Univ. Of Science and Tech., Seoul, Korea*

Abstract

Optical camera communication (OCC) is an extension of Visible Light Communication. Different from traditional visible light communication, optical camera communications is an almost no additional cost technology by taking the advantage of build-in camera in devices. It was became a candidate for communication protocol for IoT. Camera module can be easy attached to IoT device, because it is small and flexible. Furthermore almost smartphone equip one or two camera for both back and font side with high quality and resolution. It can be utilized for receiving the data from LED or positioning. Actually, OCC combines illumination and communication. It can supply communication for special areas or environment where do not allow Radio frequency such as hospital, airplane etc. There are many concept and experiment be proposed. In this paper we proposed utilizing Android smart-phone camera for receiver and introduce new approach in modulation scheme for LED at transmitter. It also show how Manchester coding can be used encode bits while at the same time being successfully decoded by Android smart-phone camera. We introduce new data frame format for easy decoded and can be achieve high bit rate. This format can be easy to adapt to performance limit of Android operator or embedded system.

Keywords: *Optical Camera Communication (OCC), Manchester Coding, Rolling Shutter, OpenCV, Template Matching.*

1. INTRODUCTION

Optical camera communication (OCC) is an extension of Visible Light Communication. Compared to another communication system, OCC system can be deployed easily because it utilize build-in camera on smartphone for receiver. The LED which is used for illumination, can be modified easily to transmit data. All the material are ready for OCC system. But current bit rate of OCC is still low but it is enough for sending a promotion information or position data. And it can be improved by increase camera resolution, optimal coding method or using logical data frame format.

Manuscript Received: Sept. 14, 2015 / Revised: Oct. 12, 2015 / Accepted: Oct. 30, 2015
Corresponding Author: seonhee@seoultech.ac.kr
Tel: +82-2-970-6426
Dept. Of Electronic & IT Media Eng., Seoul National Univ. Of Science and Tech., Seoul, Korea

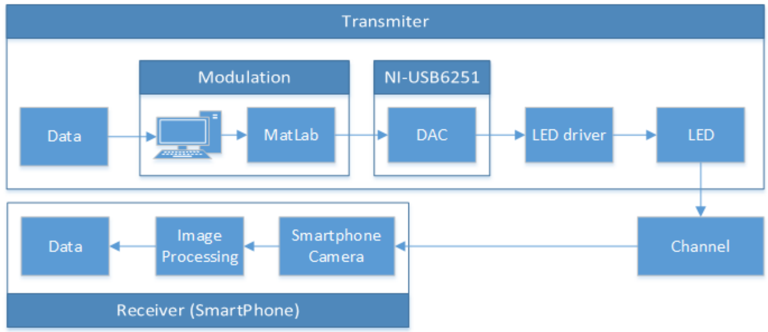

Figure 1. OCC structure

The OCC system use image processing technology for decode data and OOK cell frame modulation. LED is controlled to transmit data in the form of digital On-Off signal of illumination using On-Off pulses. A camera captures image frame of the LED which are then individually processed and sequentially decoded to retrieve data. In order to demodulation data transmission, a histogram matching algorithm is implemented using OpenCV library. Ones of the most adventures of this Library is image analysis techniques which can be used to spatially separate signal and remove interference from ambient light. The decoded processing have to finish the before the new frame come.

Two image sensor types widely used in cameras are Charge Coupled Devices (CCD) and scientific Complementary Metal Oxide Semiconductors (CMOS). Both types of sensor accomplish the same task of capturing light and converting it into electrical signals. There is a number of similarities between the two technologies, but one major distinction is the way each sensor reads the signal accumulated at a given pixel. In which every sensor type needs differences in readout modes impact the exposure timing, illumination, and triggering of cameras and light sources in photograph.

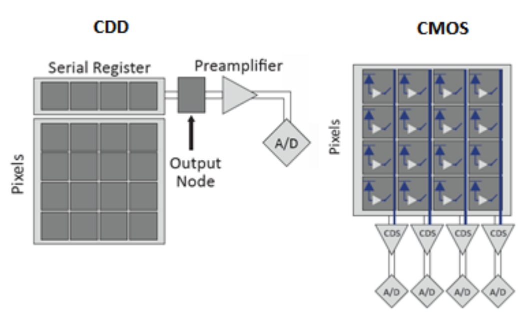

Figure 2. Image sensor model

To get a photo, every pixel requires equal duration to absorb light intensity, called integration or exposure time that is defined by duration from shutter-open to shutter-close. There are two shutter machine correspond to two kind of the image sensor. Global Shutter is widely used in CCD image sensor. In image that uses a global shutter, the entire image is reset before integration to remove any residual signal in the sensor wells. The wells (pixels) then accumulate charge for some period of time, with the light collection starting and ending at exactly the same time for all pixels. At the end of the integration period (time during which light is collected), all charges are simultaneously transferred to light shielded areas of the sensor. The light shield prevents further accumulation of charge during the readout process. The charges are then shifted out of the light shielded areas of the sensor and read out. A commercial Camera can be generated 30 fps (frame per second). Because of the limit of frame rate, OCC system which use global shutter camera, cannot achieve high bit rate.

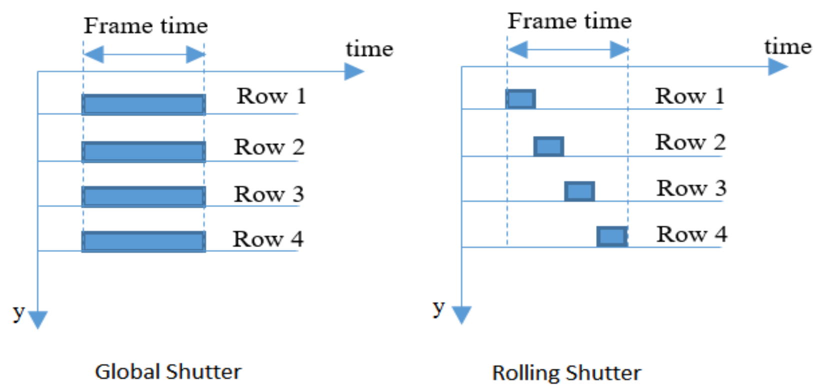

Figure 3. Shutter Machine model

In contract, a CMOS imaging chip is a type of active pixel sensor made using the CMOS semiconductor process. Extra circuitry next to each photo sensor converts the light energy to a voltage. Additional circuitry on the chip may be included to convert the voltage to digital data. Most CMOS image sensor are equipped with column – parallel readout circuits, which simultaneously read all pixels in a row into a line memory. The readout proceeds row by row, sequentially from top to bottom. All pixels do not exposed at the once time, it is difference from every row. On activation, each scanline of the sensor array is exposed, sampled and stored sequentially. Various effects can be observed due to the rolling shutter operation such as skew seem in image if a moving object. In fact, rolling shutter effect is one of distortion in photography but this effect can be utilized in OCC system and it improves OCC bit rate. This paper only focus on rolling shutter camera.

Material in this paper include: one commercial LED controlled by NI USB-6251, Galaxy tab SM-T311 for short range OCC, and LG G2 for long distance OCC, and positioning.

The paper is organized as follows. In section 2 simulation rolling shutter, calculate vertical frequency of camera. In Section 4 describe data frame structure. In section 4 implement experiment and in final section is conclusion and our future work.

2. ROLLING SHUTTER SAMPLING

Modeling Rolling shutter as Figure 4, assume that light exposure time of every row is equal and exposure and readout time is constant.

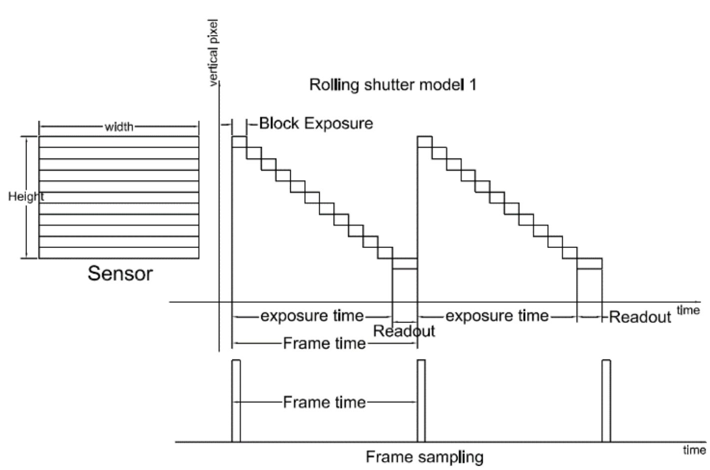

Figure 4. Rolling Shutter model

Based on the model, we have:

$$vertical\ frequency\ of\ sensor\ (f_v) = \frac{1}{row_{exposure}} \quad (1)$$

$$=> f_v = \frac{sensor\ hight * frame\ rate}{1 - readout * frame\ rate}\ (Hz) \quad (2)$$

$$T_s = row_{exposure} = \frac{1}{f_v} = \frac{1 - readout * frame\ rate}{sensor\ hight * frame\ rate}\ (s) \quad (3)$$

Assume that a LED has on-off frequency f_{signal}:

$$s(t) = A * sgn[\sin(2 * pi * f_{singal} * t)] \quad (4)$$

$$pulse\ width = {}^{1}/_{f_{signal}}\ (s) \quad (5)$$

Vertical Intensity Image of the LED can be expressed

$$pixel\ intensity = r(t) = s(t) * \sum_{k=-\infty}^{+\infty} \delta(t - kT_s) \quad (6)$$

$$pulse\ width = \frac{1}{f_{signal}} * f_v\ (pixel) \quad (7)$$

The result denotes that rolling shutter can represent the signal with variant frequency. By determine vertical frequency of image sensor (f_v) we can represent signal waveform of transmitter. In order to calculate f_v, we need to know frame rate and readout time. But in practical, this two parameters is not stability, it changes base on light intensity. Assume that camera have rolling shutter sensor, vertical pixel intensity value which cross the LED is waveform of signal. By using Discrete Fourier transform at receiver, we have:

$$f_{signal} = f_v * location\ of\ Max(Magnitude) * \frac{1}{m} \quad (8)$$

Here *m* is amount of sample used for DFT.

$$=> f_v = \frac{m * f_{signal}}{location\ of\ Max(Magnitude)} \quad (9)$$

Vertical frequency of some variant sensor are shown in table 1. In that experiment, LED was set blinking at 1 kHz (pulse width is 25ms). Vertical frequency and pulse width of receiver signal were calculated by using (8) and (9), sequentially. There are three parameter of camera must be focused on, sensor resolution, preview frame resolution, and frame rate. Normally, a camera has high resolution sensor but it cannot generate the video at raw data from sensor because of bandwidth restriction. Thus, preview frame is the compress photo of raw photo from sensor. Vertical frequency was calculated by using data from preview frame is the frequency of alias signal. It is illustrated by LG G2 case. LG G2 has two camera. Both camera can reach 1776x1080 (px) at 30(fps) preview frame. In the experiment, Front camera gave the vertical frequency higher than back camera although its sensor resolution is lower. It is because difference compress processing from two camera. Front camera preview frame was not compressed thus vertical frequency which was calculated is from real signal. Otherwise, vertical frequency of back camera is alias signal.

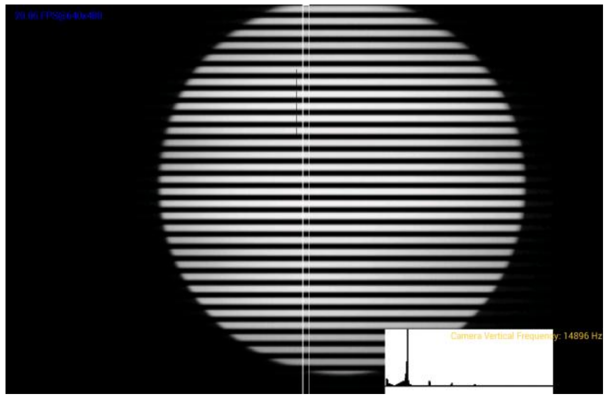

Figure 5. Implement calculate camera vertical frequency on Samsung Galaxy Tab

Table 1. Vertical frequency of same SmartPhone camera

Device	Galaxy tab		Sky A850S		LG G2	
	Back camera	Front camera	Back camera	Front camera	Back camera	Front camera
Sensor resolution	5mpx (2560x1920)	1.3mpx (1820x960)	13mpx (4192x3104)	2mpx (1600x1200)	13mpx (4160x3120)	2.1mpx (1920x1080)
Preview frame resolution	1024x768	640x480	800x480	800x480	1776x1080	1776x1080
Frame rate	30 (fps)	24 (fps)	30 (fps)	15-24 (fps)	30 (fps)	
Image sensor vertical frequency	24827(Hz)	14896(Hz)	19636(Hz)	12000(Hz)	34133 (Hz)	37925(Hz)
R(t) Pulse width	6.2 (pixel)	3.7 (pixel)	5 (pixel)	3(pixel)	8.5 (pixel)	9.4 (pixel)

In order to verify the vertical frequency we can do vice versa.

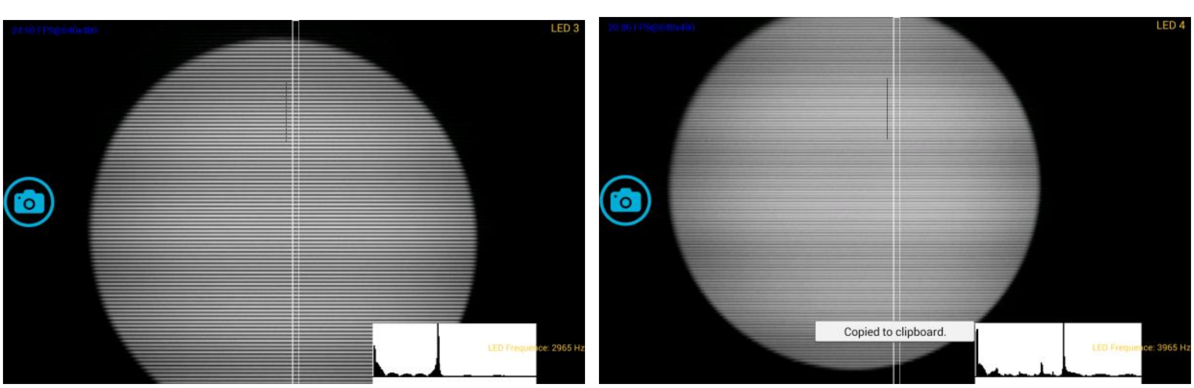

Figure 6. Detect LED-ID (LED define by Blinking Frequency)
Experiment set LED blink at 3, 4 (kHz) sequentially. Detected 2965 Hz and 3965 Hz

3. START FRAME INDICATE AND DATA FRAME STRUCTURE

As discussion above, rolling shutter can represent the blink light signal from LED. Transmit signal waveform can be represented by vertical frequency of image sensor. However camera need time for generate data and move to memory, in that time rolling shutter stop working, thus same sample will be got lost. Another issues is deal with is camera frame rate. Frame rate, is time which needs for make a frame, depended on smartphone performer and illumination emit from LED. This issues cause asynchronous of transmitter and receiver. It was shown in figure 7.

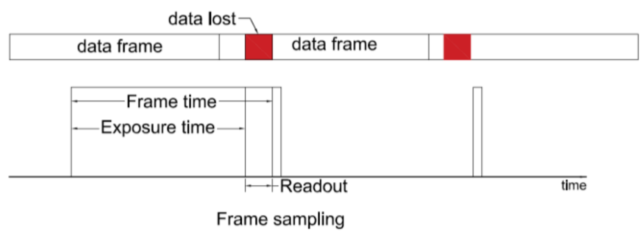

Figure 7. Data frame vs camera frame sampling

Thus data frame format must to satisfy:

- In this case, decode data mean that we find the send data from discrete camera frames. Thus, data frame must be detected easily by using image processing algorithm.
- Help receiver synchronize with transmitter.
- Avoid lost data at readout time of camera.

Encode data mean draw data to image sensor by using illumination (LED). The data is split into block of a given number of bits. Each block is encoded using Manchester coding which follows the IEEE802.3 convention. And then add start frame indicate at header and repeat transmit flag at tail of data frame. Duration of data frame equal a haft of camera frame time. Finally it is transmitted twice but repeat frame is marked by repeat flag. The flag occupy one bit of data block, bit 0 for origin block, bit 1 for repeat block. This method guarantee that at least one of the two Manchester code block is included in every preview frame and receiver can monitor data frame via repeat flag.

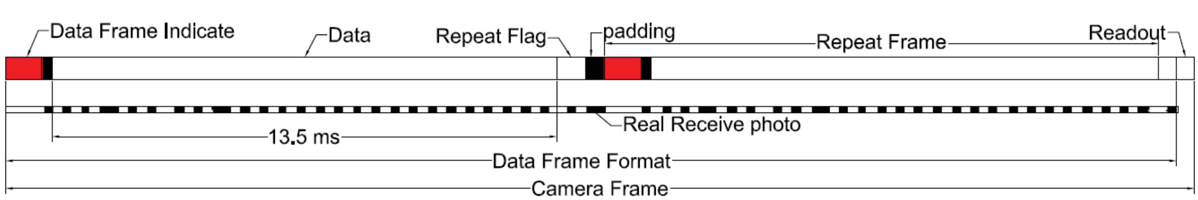

Figure 8. Data frame structure

Manchester coding is a special case of binary phase-shift keying (BPSK), where the data controls the phase of a square wave carrier whose frequency is the data rate. Such a signal is easy to generate. It specifies that for a 0 bit the signal levels will be low-high (assuming an amplitude physical encoding of the data) - with a low level in the first half of the bit period, and a high level in the second half. For a 1 bit the signal levels will be high-low.

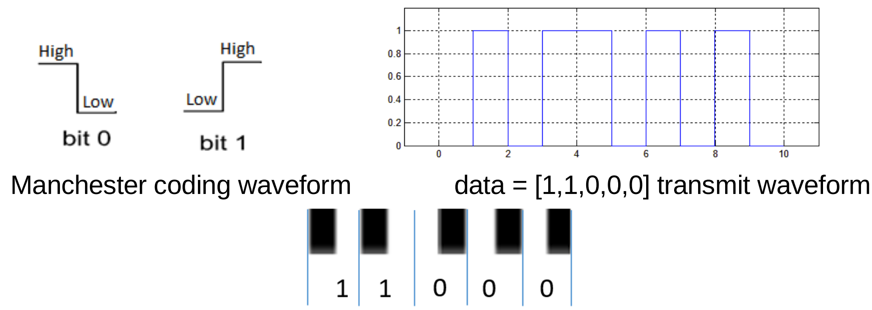

Figure 9. Manchester encode and decode

Manchester coding uses two sample hence start frame indicator has to have four sample. It help distinction between indicator and another pulse enough for distinguishable. In this paper, we suppose template matching for detect the indicator.

$$Corr(x,y) = \sum_{x',y'} T(x',y') * I(x+x', y+y')$$

Here T(x,y) is indicator template, $I(x,y)$ is camera frame.

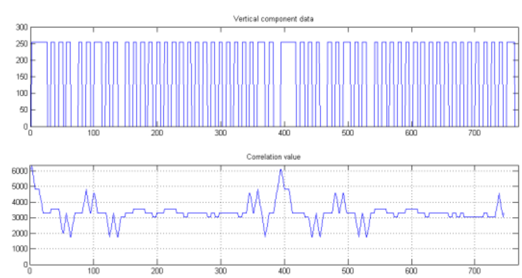

Figure 10. Correlation coefficient of SFI

4. IMPLEMENT AND EXPERIMENT PERFORMANCE

4.1 Transmitter

Text messages is 7 bit ASCII characters. It was decoded to binary stream and group each 27 bits to data block. Each data block is encoded by Manchester coding. Then SFI and repeat flag are added to head and tail of Manchester coded block, sequentially. This signal used for controlling LED.

4.2 Receiver

Camera get discrete frame every 1/30 second (suppose camera frame rate is 30 fps). Thus, decode processing must faster than 1/30 second. Because data block duration equal a half of data frame, there are two SFI in image. It is showed in figure 10, correlation coefficient reach maximum at two position. Thus, one position need to eliminate by limit detecting area. This work also reduce calculation. Positon of SFI is position of correlation coefficient where it reach maximum. Follow SPI segment is data segment. Because of the asynchronous between transmitter and receiver, the lost data which occur either of two data block (origin or repeat) will increase after every camera frame. When one data block is completely lost, there will be two data blocks in one camera frame. If repeat flag of fist block is bit 1, next block must be not repeat version of fist block and repeat version of this block will appear in next camera frame but it cannot be detected.

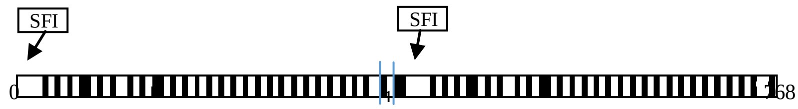

Figure 11. Two data block in one camera frame

4.3 Experiment performance.

In this section, we implemented the proposed data structure on experiment application. In the experiment, a Samsung galaxy tab T310 Android smartphone with a 5 megapixel camera is used as a receiver, and an LED with 25 cm diameter is used as transmitter. This system is evaluated by transmitting text messages from an LED to Android smartphone. Transmitter application is implemented on Matlab. Transmit data is encoded by using Manchester coding method. Data block occupy 13.5ms include 54 pulse for 27 bit. At receiver, an Android application enables to get frame from smartphone camera. Each frame is applied image processing algorithm to detect SFI and decode data. As discussion above, each pulse correspond with 6 pixels. Thus, Data block occupy 324 pixel. Calculations show that on average the detection and decoder requires 15ms. Furthermore, parallel processing was applied in the application. Thus, Detect and decode operation is not effect on camera operation. It means that detect and decode operation had completed before new frame came. Decode is illustrated in figure 9 and SFI detection is illustrated in figure 10. The result of the tests is showed in table 2. A demonstration of the tests can be seen in [3]

Table 2. Experimental specification

Parameter	Value
Camera model	Galaxy SM-T311
Shutter mode	Rolling Shutter
Average frame rate	30 fps
Preview Resolution	1024x768
Encode scheme	Manchester coding
Carry frequency	2kHz
Demodulation method	Image processing
Manchester symbol duration	0.5ms
Synchronization method	SFI & repeat flag
Data block	27 bit
Data block duration	13.5ms
Bit rate	Up to 1 kbps
LED Shape	circle
LED diameter	28cm
LED power	220V-30W
Distance from LED to smartphone	30cm

5. CONCLUSION AND FUTURE WORK

In this paper, we introduced data frame structure for unidirectional OCC system where no synchronization required, and describe how it deal with asynchronous between transmitter and receiver, and readout time of camera. The bit errors cause by asynchronous between transmitter and receiver, can be corrected by monitoring the repeat flag. This data frame structure adapted well for variant camera frame rate in range 15 to 30 (fps), however it cannot adapt for variant preview resolution. In this experiment we must to fix preview resolution at 1024x768. Bit rate reach up to 1 kbps with this resolution. The higher bit rate can be achieved with high preview resolution. Another issues is about increasing distance between transmitter and receiver. Normally bit rate depend on amount of the pixel which LED occupy on image sensor. When receiver moves to far transmitter, the area of LED on image senor will decrease. This will not only decrease bit rate but also effect on synchronization. The solution for two issues will be presented in our next work.

We are also planning a paper that shows how we can extend rolling shutter sampling effect for LED definition (LED ID) and using for indoor positioning,

ACKNOWLEDGEMENT

This study was supported by the Research Program funded by the Seoul National University of Science and Technology

REFERENCES

[1] R.D. Roberts, “Undersampled Frequency Shift ON-OFF Keying (UFSOOK) for Camera Communications (CamCom),” submitted to Wireless and Optical Communication Conference 2013 (WOCC 2013), May 2013.

[2] Jinwei Gu, “Coded Rolling Shutter Photography: Flexible Space-Time Sampling,” 2010 IEEE International Conference on Computational Photography (ICCP).

[3] Nobuo Iizuka, “Image Sensor Communication (ISC): A New Way of Visible Light Communication (VLC),” 17th International Display Workshops 2010 (IDW 2010), December 2010.

[4] IEEE 802.15.7 Standard for Local and Metropolitan area networks. (2011). Part 15.7: Short-range Wireless Optical Communication Using Visible Light.

[5] Demonstration video *https://youtu.be/kMOOxouDYK8*

[6] The IEEE 802.15.7a OCC study group: *https://mentor.ieee.org/802.15/documents?is_dcn=DCN%2C%20Title%2C%20Author%20or%20Affiliation&is_group=0led.*