Northumbria University
NEWCASTLE

Flicker-free Multi-channel Transmitter Orientation in Camera based Optical Wireless Communications

Shivani Rajendra Teli[1], Stanislav Zvanovec[1], and Zabih Ghassemlooy[2]
[1]*Faculty of Electrical Engineering, Czech Technical University in Prague, Prague, 16627, Czech Republic,*
[2]*Faculty of Engineering and Environment, Northumbria University, Newcastle-upon-Tyne, NE1 8ST, UK*
{telishiv; xzvanove}@fel.cvut.cz, z.ghassemlooy@northumbria.ac.uk

Abstract: We demonstrate the camera based optical wireless communications using flicker-free multi-channel transmitter orientation that provide 100 % success of reception over orientation angle of up to 30˚ at 200 and 400 µs camera shutter speed.

1. Introduction

Camera receiver (Rx)-based optical wireless communication (OWC) systems are also known as optical camera communications (OCC) in the IEEE 802.15.7rl Task Group, which describes the potentials of OCC within OWCs [1]. While visible light communication systems using high-speed photodetectors have been aimed at high data rate indoor communications, OCC schemes are intended for low data rate applications such as Internet-of-things (IoT), localisation, etc. [2]. The rolling-shutter (RS) capturing mode of a camera offers sequential row-by-row (i.e., line-wise) scanning of the entire image, thus offering flicker-free OCC. An RS based single-channel pattern decoding scheme was proposed in [3] for translational or rotational motions of a transmitter (Tx). However, the scheme lacked the angular rotation of the Tx or the Rx and its effect on communication links was not investigated. Non-line-of-sight (NLOS) diffused OCC links based on reflections was reported in [4], which achieved 1 kbps flicker-free transmission. However, OCC systems supporting angular orientation of both Tx and Rx as well as flicker-free and multi-channel transmission in indoor scenarios till need investigating, which is the subject of this paper.

We propose an experimental OCC system, which can be used in indoor short-range IoT applications and present results for the data throughput and transmission success rate for a range of orientation angles θ of Tx, different transmission spans L and shutter speed (SS).

2. Flicker-free Multi-channel OCC System

Figure 1 shows the proposed flicker-free multi-channel OCC system. On the Tx side, a Arduino Uno microcontroller was used as the LED driver, which assigns a number of pixels (N_{pixels}) to chips (N_{chips}) and channels ($N_{channels}$). The data in the form of non-return-to-zero on-off keying (NRZ-OOK) is mapped to the LED addresses of a 8 × 8 neopixel LED array (size 7.2 × 7.2 cm^2) using 8 different $N_{channels}$ at a frequency $f_s = (t_{chip})^{-1}$, where t_{chip} is a 1-bit time per chip with a maximum value of 2.5 ms to ensure flicker-free transmission at f_s of 400 Hz. Inset (a) in Fig. 1 shows the assembled Tx unit with a grid for channel separation along with a diffuser and inset (b) shows the LED array configuration with dimensions.

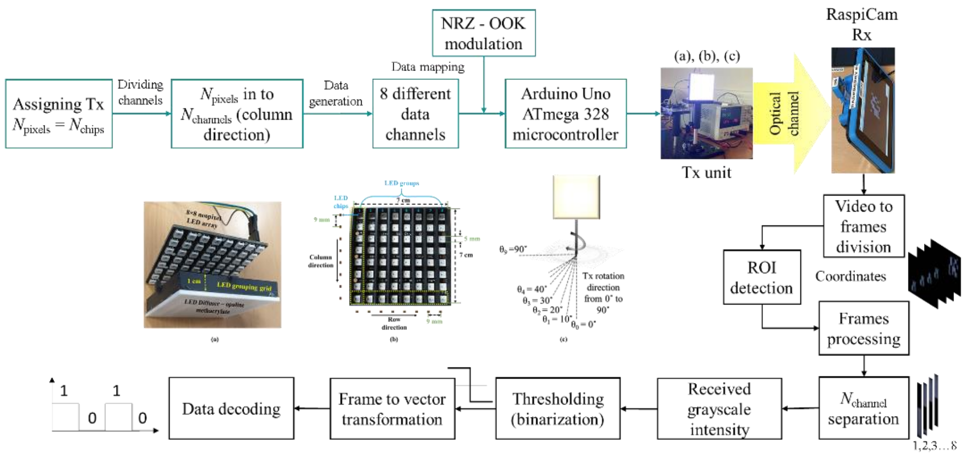

Figure 1. Multi-channel OCC data processing flow diagram: insets (a) Tx unit assembled with grid and a diffuser, (b) a LED array configuration and (c) Tx orientation.

On the Rx side, a Raspberry Pi camera (RaspiCam) with the RS-based capturing mode is used to capture a video stream of the Tx with 1920 × 1080 pixels resolution, 30 fps capture speed, SS of 200 and 400 µs and L in the rage of 10 to 100 cm. In order to support rotational movements, we used θ = 0˚ to 90˚ with a change of 10˚ at the Tx, inset (c) in Fig.1. Data processing follows the region of interest (RoI) detection and $N_{channel}$ separation, and image processing is performed on the cropped images, which are then converted to the grayscale to retrieve the intensity profile. The threshold level is set based on the average of the received image intensity profile within the RoI. Following thresholding, binarization of the data frames is performed to convert the frame into vector transformation. This process is applied to the remaining frames for decoding the transmitted data bit streams.

3. Experiment results and analysis

Figure 2 shows the captured image frames, its quantized intensity (Fig. 2 (b)) and grayscale intensity profiles (Fig. 2 (c)) of the detected data for L of 20 up to 100 cm and SS of 200 and 400 µs. The dotted yellow box in the original image frames is the ROI, which fills only the captured Tx within the full image frame. The clear and sharp distinction between the data lines can be seen at SS of 200 µs, while the lines get a bit saturated for 400 µs. On the other hand, due to rotation of the Tx its shape changes, which results in loss of data bits (see Fig. 2 (a)).

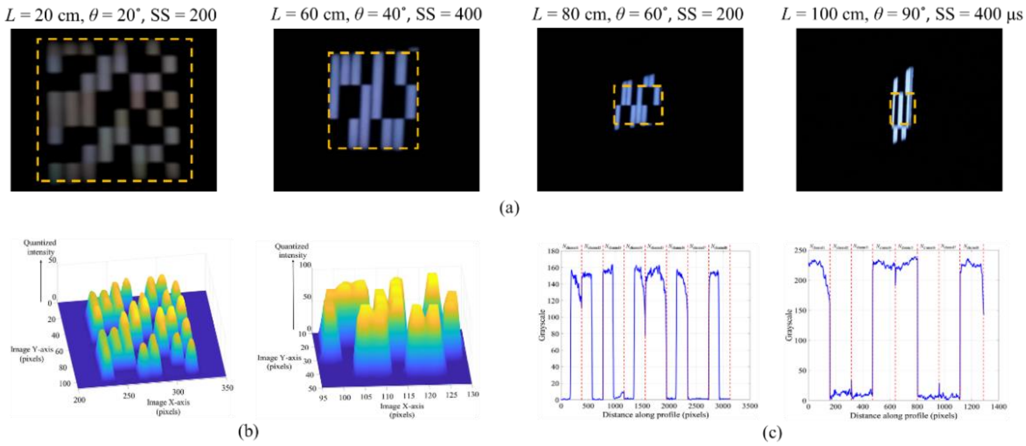

Figure 2. Multi-channel OCC (a) captured images, (b) the quantized intensity profiles and (c) grayscale intensity profiles for data detection.

Based on the received bits N_{bits} in the image frames, the data throughput is calculated as $N_{channel} \times N_{bits} \times$ (fps/2). Figure 3 (a) shows the data throughput and Fig. 3 (b) and (c) shows the success of reception for SS of 200 and 400 µs with respect to θ over L. The maximum data throughput of 0.96 kbps is achieved for θ of 0˚ and 10˚ and L of 10 and 20 cm while a minimum data throughput of 0.12 kbps is achieved for θ of 90˚ and L of 30 up to 100 cm. It can be seen that, 100 % success is achieved for θ of 30˚ and 20˚ and L up to 60 cm at SS of 200 and 400 µs.

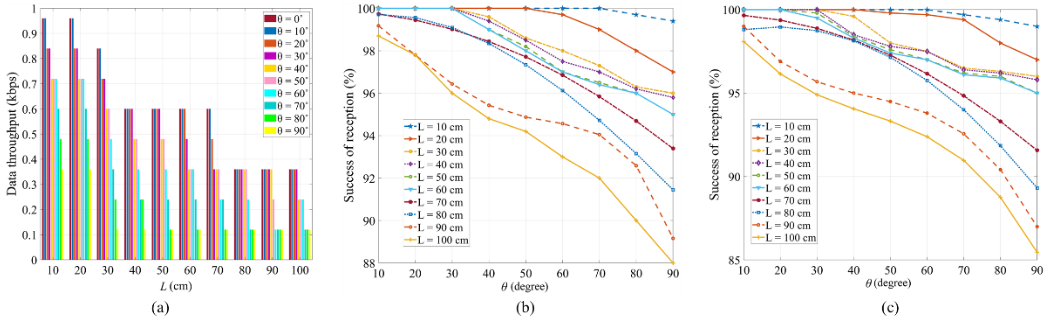

Figure 3 Multi-channel OCC performance analysis: (a) the data throughput with respect to θ over L, (b) and (c) success of reception at SS of 200 and 400 µs with respect to θ over L.

4. Conclusion

In this paper, we proposed a simplified Tx design, which provide flicker-free and multi-channel short-range OCC links for IoT applications. Despite the small area of the Tx, 100 % success of reception long with θ up to 30˚ at L of 60 cm was experimentally demonstrated for indoor short-range IoT links. The scheme will be further extended with multiple Tx's and multi-channel schemes using robust decoding algorithm.

5. References

[1] M. J. Jang, "IEEE 802.15 WPAN 15.7 amendment-optical camera communications study group (SG 7a)," 2019 [Online accessed February 2020].

[2] Y. Yang, J. Hao and J. Luo, "CeilingTalk: lightweight indoor broadcast through LED-camera communication," *IEEE Transactions on Mobile Computing*, vol. 16, no. 12, pp. 3308-3319, 1 Dec. 2017.

[3] P. Luo et al., "Experimental demonstration of RGB LED-based optical camera communications," *IEEE Photonics Journal*, vol. 7, no. 5, pp. 1-12, Oct. 2015.

[4] N. B. Hassan et al., "Non-line-of-sight MIMO space-time division multiplexing visible light optical camera communications," *Journal of Lightwave Technology*, vol. 37, no. 10, pp. 2409-2417, 2019.