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광학 카메라 통신 시스템의 현실적 시뮬레이션 프레임워크

두트롱홉•, 유 명 식°

A Framework for Realistic Simulations of Optical Camera Communication Systems

Trong-Hop Do•, Myungsik Yoo°

요 약

광학 카메라 통신 (OCC)에서 LED 어레이는 카메라가 수신 할 가시광 신호를 전송하는 데 사용된다. OCC 시스템의 성능은 LED 휘도, 배경 조도, 카메라 노출 설정, LED 및 카메라 이동 속도 등 통신 채널의 많은 매개 변수에 따라 달라진다. 이러한 많은 매개 변수의 영향을 체계적으로 조사하려면 OCC 시스템에 대한 시뮬레이션이 필수적이다. 본 연구에서는 광도 측정, 카메라 형상, 디지털 이미지 획득 및 광학 이미지 통신을 포함한 여러 분야의 기본적인 원리에 대해 서술하고, OCC 시스템을 분석하기 위한 요구 사항을 살펴본다. 이러한 원리와 요구 사항에 따라 OCC 시스템의 현실적인 시뮬레이션을 위한 프레임워크를 제안한다.

Key Words : LED, optical, camera, communication, simulation

ABSTRACT

In optical camera communication (OCC), LED arrays are used to transmit visible light signal which will be received by cameras. The performance of OCC system is dependent on many parameters of the communication channel including LED luminance, background illuminance, camera exposure setting, LED and camera movement speeds, etc. To systematically examine the impact of those many parameters, simulations on OCC system are compulsory. In this study, fundamental principles in multiple fields including photometry, camera geometry, digital image acquisition, and optical image communication are provided and requirements for examining a OCC system are investigated. Then, based on these principles and requirements, a framework for realistic simulations of OCC system is provided.

Ⅰ. Introduction

In recent years, thanks to the rapid development of light emitting diode (LED) and camera, optical camera communication (OCC) has been emerging as a promising candidate for short to middle range communication technology in many applications[1-3]. Especially, OCC has many advantages to be used for vehicle communication in intelligent transport system and autonomous vehicle network. The

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• First Author : Trong-Hop Do, School of Electronic Engineering, Soongsil University, Seoul, Republic of Korea, dotronghop@gmail.com, 학생회원
° Corresponding Author : Myungsik Yoo, School of Electronic Engineering, Soongsil University, Seoul, Republic of Korea, myoo@ssu.ac.kr, 종신회원
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clearest advantage is the availability of LED and camera in all vehicles. In OCC, LED lamps and dashboard cameras available in vehicles can be used as transmitter and receiver. Compared to radio frequency (RF), no license needed for using visible light for vehicle communication and also no interference with other RF communication. The interference between vehicles is not a problem thanks to the line of sight properties and the spatial separability of the camera. Because of these advantages, there have been a lot of studies on OCC in recent years. However, the research on OCC is still at a beginning phase and the capability of OCC in different situations need to be examined more. The problem is that the performance of OCC system is dependent on many parameters of the communication channel. For example, at the receiving side, the quality of the received signal, which is the LED panel image captured by the camera, is determined by LED luminance, background illuminance, physical characteristics of LED panels, camera exposure setting, weather condition, LED and camera movement, and many other parameters. With experiment, only a small set of parameters with limited ranges of values can be tested. Systematic and intensive analysis of the performance of OCC system can only be performed by conducting simulations. There are studies on OCC using simulated data but the simulation environment in those studies are far from being realistic and thus cannot provide fair evaluation of the OCC system. The reason for this is because simulating OCC system requires replicating images of LED arrays with many effects that involving deep knowledges in photometry, camera geometry, and digital image acquisition. In studies on OCC, only communication aspects are considered while details on photometry and digital image acquisition are usually overlooked.

In this study, firstly the architecture of OCC system and requirements for a realistic OCC simulation are explained. Then, fundamental principles in photometry and digital image acquisition are provided to form a framework for a realistic simulation of OCC system.

Ⅱ. OCC System Architecture and Simulation Requirements

2.1 System architecture

An OCC system with many steps is described in Fig. 1. At the receiver side, the transmitted bit stream is decoded, modulated, and then transmitted using an LED panel. The digital bit 0 and 1 are represented by the status Off and On of LEDs in the panel. At the receiver side, a camera is used to capture the image of the LED panel. Then, in the demodulation step, the LED panel image is processed to extract the data embedded in the image. After decoding, the transmitted data is received.

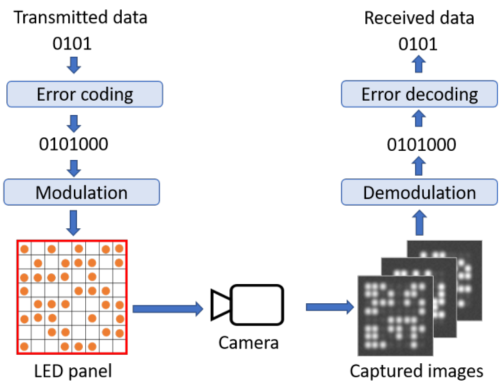


Fig. 1. OCC system architecture

2.2 Requirements for a realistic OCC system simulation

The requirements for a realistic OCC system are described in Fig. 2. From the communication aspects, the simulation needs to replicate the power strength, noise, and spatial effects on the system performance. More specifically, to replicate the effect of power strength, the correct greyscale of LED and background in the image corresponding to different levels of LED and ambient light brightness must be determined. Regarding noise effect, blooming interference between LEDs in the array and motion blurs effects must be replicated in the simulated image. As for the spatial effect, angle distortion, size and position of LEDs corresponding to different position and pose of the camera and

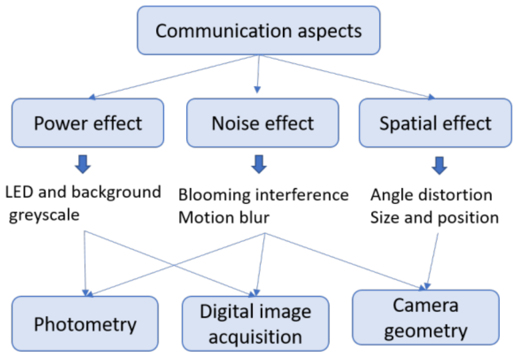


Fig. 2. Simulation requirement

LED need to be replicated precisely. Replicating these effects requires understandings in photometry, digital image acquisition, and camera geometry, which will be presented in the next section.

Ⅲ. Fundamental Principles in Camera Geometry, Photometry, and Digital Image Acquisition

3.1 Camera geometry

To replicate the image of LEDs, the pinhole camera model depicted in Fig. 3 is used. A point with real world coordinate X would have image coordinate x related to X through the camera geometry equation:

$$\lambda x = K[R\ t]X \tag{1}$$

where x is a arbitrary scalar, K is the camera intrinsic matrix which encompass focal length, image sensor format, and principal point of camera, R is the camera rotation matrix, and t is the camera translation vector.

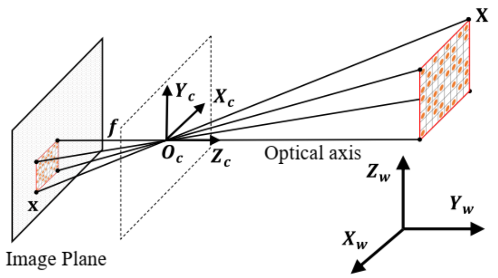


Fig. 3. Pinhole camera model

3.2 Photometry

The intensity of LED radiated light is measured in luminance, denoted as L_v, which indicates how much luminous power is perceived by the human eye looking at the surface from a particular angle.

The intensity of the ambient light illuminating the LED surfaces is measured in illuminance, denoted as E_v, which indicates how much the incident light illuminates the surface. Assuming that the ambient light illuminance is E_v and the reflectance of an object is R; the luminance of the reflected light from that object is given as:

$$L_v = \frac{E_v \times R}{\pi} \tag{2}$$

3.3 Digital image acquisition

The acquisition process of digital image is described in Fig. 4. The greyscale value g at a pixel in the image sensor at a given ISO speed S set by the camera is determined as:

$$g = 118 \times \left(\frac{H}{H_{SOS}}\right)^{1/\gamma}, \tag{3}$$

where H is the luminous exposure, which corresponds to the amount of light coming to the pixel, $H_{SOS} = 10/S$ is the indicated luminous exposure required at the ISO speed S to achieve the greyscale value 118, and γ is the gamma value used for gamma encoding.

The light coming from an Off LED to the image sensor is the ambient light reflected from the LED surface. Therefore, the luminous exposure of an Off LED pixel is given by:

$$H_{led0} = \frac{10 E_v R_{led} t}{K \pi N^2}, \tag{4}$$

where E_v is the illuminance of the ambient light, R_{led} is the reflectance of the LED surface, t is the

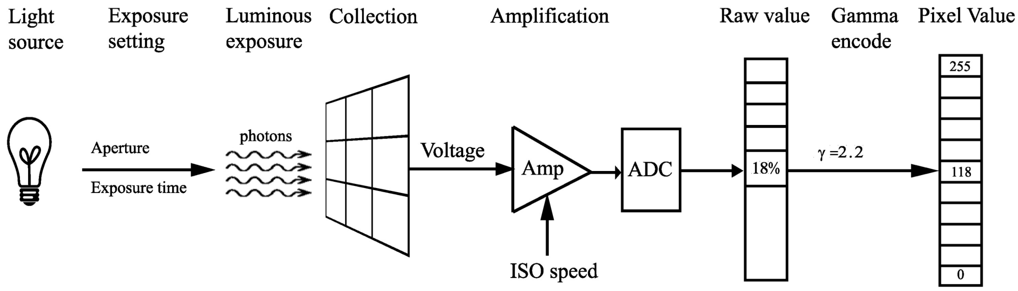


Fig. 4. Digital image acquisition

exposure time of the camera, N is the f-number of the lens, and K is the reflected-light meter calibration constant determined by camera manufactures.

The light coming from an On LED to the image sensor is the combination of the light emitted by the LED and the ambient light reflected from the LED surface. Therefore, the luminous exposure of an On LED pixel is given by:

$$H_{led1} = \frac{10E_vR_{led}t}{K\pi N^2} + \frac{10L_vt}{KN^2}, \tag{5}$$

where L_v is the luminance of LED.

The luminous exposure of background is given as:

$$H_{bg} = \frac{10E_vR_{bg}t}{K\pi N^2}, \tag{6}$$

where R_{bg} is the average reflectance of background.

3.4 Blooming interference

Blooming interference effect is replicated using Gaussian blur function as:

$$\hat{I} = I * G \tag{7}$$

where I denotes the original image, $\hat{I}$ denotes the image with blooming interference effect, $*$ denotes convolution operation, G is the gaussian blur point spread function given as:

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}, \tag{8}$$

where x is the distance from the origin in the horizontal axis, y is the distance from the origin in the vertical axis, and σ is the standard deviation of the Gaussian distribution.

Ⅳ. Framework for OCC Simulation and Simulation Results

The framework for OCC simulation is described in Fig. 5. Given the assumptions of LEDs and camera geographic location, the image coordinate of LEDs can be replicated using pinhole camera model. Given the assumptions of LED, background lighting condition, and camera exposure setting, the greyscales of each pixels is determined using digital image acquisition equations. After that, the simulated image is convolved with the gaussian blur function to replicate the blooming interference effect.

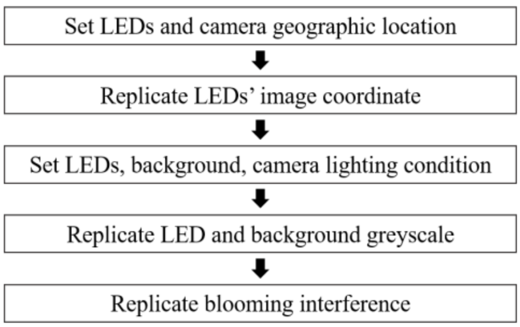
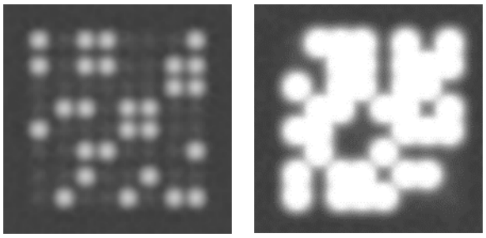


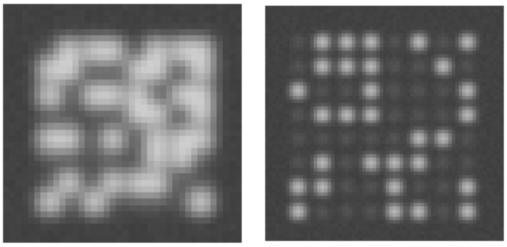
Fig. 5. Digital image acquisition

The proposed algorithm is implemented using Matlab. The cropped simulated images of LED panels at different conditions are shown in Fig. 6, 7, and 8. Through Fig. 6, it can be seen that the greyscale of LEDs in different lighting conditions and the blooming interference effects are replicated in a realistic way. Other system parameters such as LED interval and communication distance are also replicated in the images as shown in Fig. 7 and 8.



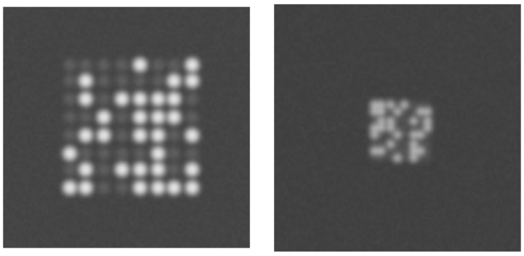
(a) Low intensity image (b) High intensity image

Fig. 6. LED panel image at different lighting condition



(a) Short LED interval (b) Long LED interval

Fig. 7. LED panel image at different LED interval



(a) Short distance (b) Long distance

Fig. 8. LED panel image at different commutication distance

V. Conclusion

This paper proposed a framework for simulating LED array images, which is the received signal in OCC system. Fundamental knowledges in various field including photometry, camera geometry, digital image acquisition, and optical camera communication are collected to provide a framework for realistic simulation of OCC system.

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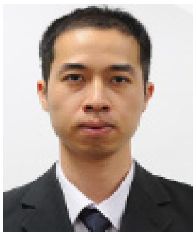
두트롱홉 (Trong-Hop Do)



Trong-Hop Do received the B.S. degrees in Mathematics and Computer Science from University of Science Ho Chi Minh City, Vietnam, in 2009, and his Ph.D. in information and telecommunication from Soongsil University, Seoul, Korea, in 2015. His research interest includes visible light communication, wireless sensor network, vehicle communication and sensing.

유 명 식 (Myungsik Yoo)

Myungsik Yoo received his B.S. and M.S. degrees in electrical engineering from Korea University, Seoul, Republic of Korea, in 1989 and 1991, and his Ph.D. in electrical engineering from State University of New York at Buffalo, New York, USA in 2000. He was a senior research engineer at Nokia Research Center, Burlington, Massachusetts. He is currently a professor in the school of electronic engineering, Soongsil University, Seoul, Republic of Korea. His research interests include visible light communications, sensor networks, Internet protocols, control, and management issues.