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Optical Camera Communications: Future Approach of Visible Light Communication

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ABSTRACT

As an extension of Visible Light Communication, Optical Camera Communications (OCC) will be a promising service for smart devices. Especially in line of sight marketing service and indoor localization application, by using camera which exists in smart devices, small amount of data (url link) can be broadcasted or find direction from the illumination system. This paper introduces the operation of wireless communications technology that transmits optical information from optical light source to camera, called Optical Camera Communications.

Key Words : OOK, computer vision, VLC, optical camera communications

Ⅰ. Introduction

The increasing embedded rate of high pixel build-in camera in cell phones and smart devices have created a big opportunity to build a camera based communication system. Camera based communication[1,2] system is a highly directional transmission system by using the optical channel, which is different from traditional RF channel. The directional transmission advantage can provide potential safety advantages and special environment. It will be promising future direction which combines illumination and communication. Different from traditional visible light communication[3], optical camera communications is an almost no additional cost technology by taking the advantage of build-in camera in smart phone. Although the frame rate of smart phone camera is common at 30 fps, with the increasing pixels resolution as the demand of the market and MIMO approach[4,5], the throughput performance will not be the big obstacle.

The remaining of paper is structured as follows. The overview of optical camera communications will be presented in section 2. The performance experiment is presented in section 3. Section 4 concludes remarks of the works and contributions.

Ⅱ. OCC Architecture

The structure of optical camera communications is shown in Figure 1 as following. Because of discrete signal by receiving picture, OCC system requires its own encoding scheme that suitable for imaging in the receiver side. So the OOK based modulation will be the candidate. After modulation, encoded data will be transmitted through optical channel to the global or rolling shutter camera receiver. The modulation and demodulation of optical camera are presented in Figure 2.

The OCC system is a combination of the reliance on computer vision algorithms for tracking and OOK cell frame modulation. LED array are controlled to transmit message in the form of digital information using ON-OFF signaling with ON-OFF

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pulses (ON = 1 bit, OFF = 0 bit). A camera captures image frames of the LED arrays which are then individually processed and sequentially decoded to retrieve data. To demodulate data transmission, a motion tracking algorithm is implemented in OpenCV (Open source Computer Vision library) to classify the transmission pattern. One of the most advantages of proposed architecture is Computer Vision (CV) based image analysis techniques which can be used to spatially separate signals and remove interferences from ambient light. It will be the future challenges and opportunities for mobile communication networking research.

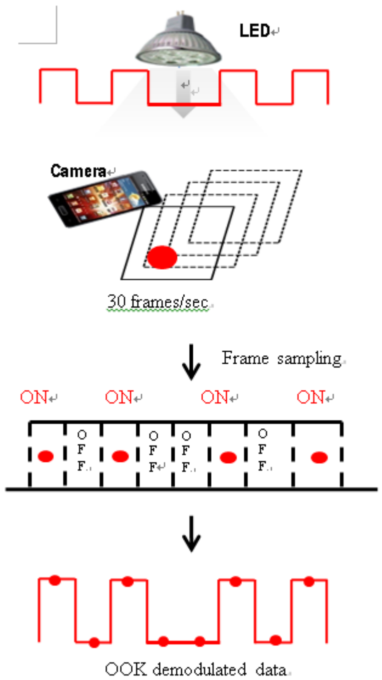

Fig. 1. Camcom architecture

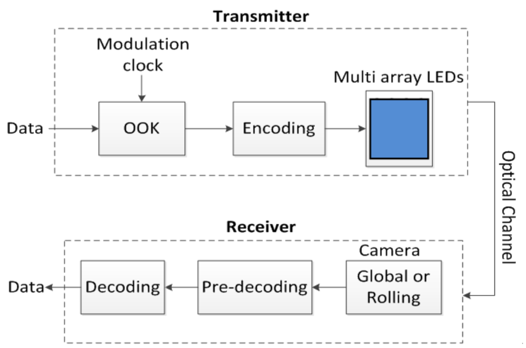

Fig. 2. Camcom transmitter and receiver structure

To get an image, every pixel requires equal duration to absorb light intensity, called integration time (Figure 3), that is defined by duration from shutter-open to shutter-close. There are two types of camera sensor which have difference in operation causing to the difference in data transmission of OCC system, as explained in Figure 3. In the global shutter mode, light integration takes place on all pixels in parallel, although subsequent readout is sequential[6]. It means all pixels are captured at the same time of shutter open to close using common Reset and common sample & hold. Then integration time is same for all pixels. In contrast, in the rolling shutter mode, light integration takes place on all pixels in sequential, and then it operates similarly as scanning function. It means all pixels are captured in equal integration time, but at different beginning and ending (different moment of shutter open and close). In case of row scanning, every pixel in each scanning row is captured at the same beginning and ending, but pixels in different rows are captured at different beginning and ending periods. It makes the difference in the operation of image generation. That is the exposed time of how the sensor get full light of global and rolling. As seen in Figure 4, the rolling shutter camera will record how state of LED changes during capturing time (rolling time), but global shutter camera can capture a static state of LED. This is important factor for modulation scheme and transmitter's structure design. The condition of shutter speed and bit modulation for global shutter and rolling shutter is shown in Table I.

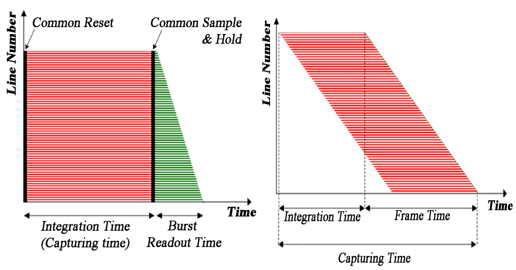

Fig. 3. Rolling shutter and global shutter operation

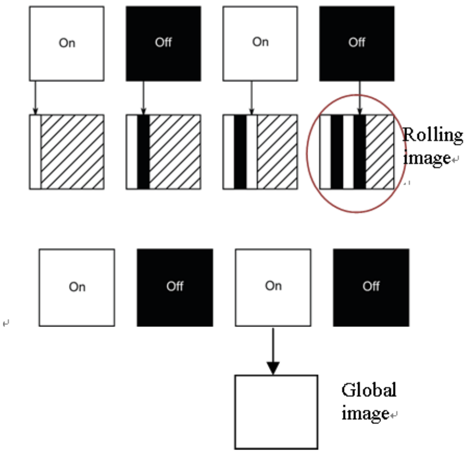

Fig. 4. Data retrieve

Table 1. Shutter condition

Shutter mode	Condition
Global shutter	Fshut>FMod
Rolling shutter	(1/N)Fshut<FMod

Where $f_{Shutter}$ is shutter speed.
f_{Mod} is Modulation rate at transmitter.
N is number of bits decoded per rolling image.

About modulation issue, this affects to the flickering and data rate OCC system. Different with RF system, the output from camera is discrete image. So the modulation data must base on the state "ON" and "OFF" of light source. The correlation function is not efficient to match the signal. Especially indoor application service flickering should be more considered because of illumination factor. To mitigate flicker, LED needs to change its state (ON/OFF) continuously and fast enough during bit length instead of ON or OFF simply during whole bit length. Modulation rate (fMod) represents how fast LEDs change their states, and must be no less than 200Hz to avoid flicker[7,8]. Rolling shutter takes advantage in use of higher modulation rate, and higher number of bits per image can be decoded. Rolling shutter is best suitable for single LED application while multi LEDs technique is no better than single LED in rolling image. On the other hand, global shutter takes advantage in use of multi LEDs. The limitation of modulation rate due to shutter speed limit is main problem. No more than one bit can be decoded per each image of LED. Global shutter is best suitable for multi array LEDs to enhance data rate.

Ⅲ. Performance Experiment

We implement OCC system based on Arduino board for LED control at transmitter and Visual Studio C# with Computer Vision library for camera control at receiver. The system configuration is shown in Tabel II. The operation of transmitter and receiver are shown Figure 5. At the transmitter side, the binary bit will control the LED ON/OFF status. The optical channel is presented as LED array status. At the receiver side, camera will sample image frame at 30fps. The sampling period must be synchronized as synchronization scheme. The receiver will detect the transmitter pattern by using

Table 2. Experiment Configuration

Parameters	Values
Camera	SPC-A4000M
LED	5W
Distance	0.5-1m
Modulation	Rooling shutter: 105Hz-120Hz Global shutter: 20Hz
Shutter speed	4kHz
Frame rate	20-30 fps

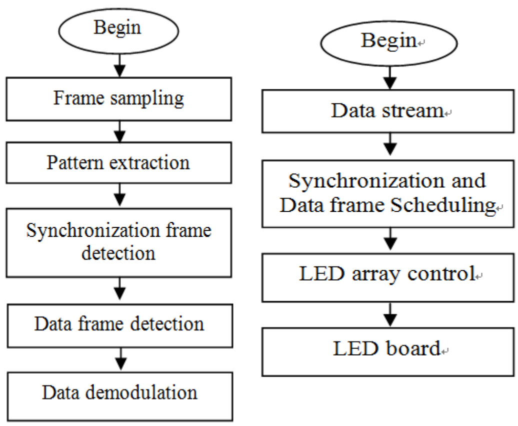

Fig. 5. a. Receiver operation b. Transmitter operation

pattern recognition of computer vision function. After extracting the transmitter pattern, the application continues classifying the cells partition and detecting status of cell of LED transmitter. Most important process in receiver is pattern recognition, we embedded Aforge computer vision library for transmitter pattern extraction.

Difference with VLC based Photodiode, the communication range of optical camera communications can be extended by zooming function of camera easily. Because the lens can increase the light absorption of Region of Interest (ROI) in image sensor. With photodiode, it is impossible.

Examples of receiving data from rolling shutter and global shutter mode are shown in Figure 6 and Figure 7. At rolling shutter mode, decoded image includes multiple decoded data bits in the rolling picture. Global shutter mode, however, decoded one data bit in every receiving image. Figure 8 and Figure 9 show the performance of implementation at rolling shutter and global shutter. For rolling shutter case we can achieve higher throughput compare with global shutter at same condition of frame rate.

Compare with VLC system, optical camera communications has higher directional characteristic. With Photodiode based VLC, the interference of ambient light will affect on the output current.

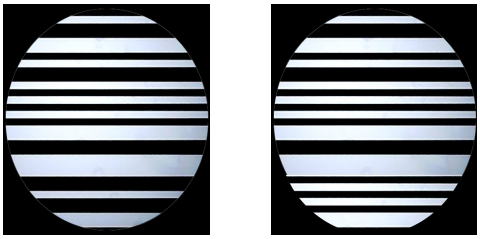

Fig. 6. Data form rolling shutter mode

Fig. 7. Data form global shutter mode

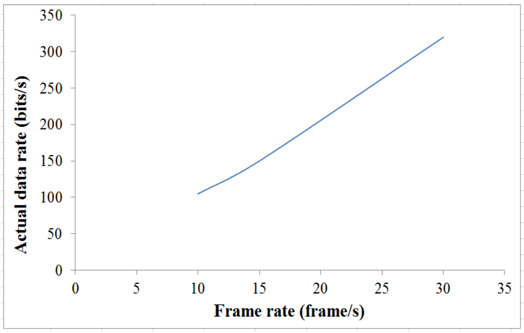

Fig. 8. Throughput performance of rolling shutter mode

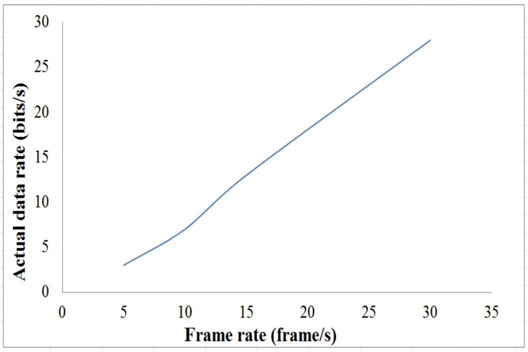

Fig. 9. Throughput performance of global shutter mode

However with image sensor based the interference is spread out so the output is just considered as a background DC gain. This is can be easily to eliminate when we select ROI of decoded cell.

Ⅳ. Conclusion

In this paper we give an overview of OCC from the architecture, operation to implementation challenges. By introducing the concept and scenario of optical camera communications, the combination of visible light communication and camera, proposed issue will be promising service.

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