Image processing technique for Optical Camera Communication

Trang Nguyen*, Nam-Tuan Le*, and Yeong Min Jang**

OCC에서의 이미지 처리 기술

Trang Nguyen*, Nam-Tuan Le*, and Yeong Min Jang**

ABSTRACT

This paper introduces the Optical Camera Communications (OCC) using image processing technique.The architecture and operation of OCC system are given. To enhance data rate which is limited by sampling operation of commercial 30fps camera, multi colors transmission technique is employed, leading to the importance of color image processing technique. Multi color encoding and image processing based decoding will be proposed in the paper.

Key Words : Visible Light Communication, Optical Camera Communication, OCC, Color Image Processing, Multi colors transmission.

요 약

본 논문은 이미지 처리 기술을 이용한 광 카메라 통신(OCC: Optical Camera Communications) 기술을 제안한다. OCC 시스템의 구조 및 동작을 제안한다. 상용 30fps 카메라의 샘플링 동작에 의해 제한되는 데이터율을 증가시키기 위해 칼라 이미지 처리기술을 이용한 멀티칼러 전송기법을 제안한다. 멀티칼라 부호화 및 이미지 처리기반의 복호화 기법을 제안한다.

I. Introduction

Recently, LED lighting and display technology have been popular in the spotlight and there have been many attempts to combine lighting infrastructure with communications technology. Visible Light Communication (VLC) offers a real alternative to wireless communication using radio frequency (RF) because the visible light spectrum is free, plentiful, and the implemental cost is actually less than equivalent radio technology.

The advances of imaging technology (including CCD and CMOS) and visible light LED present a promising vision of optical communications using camera, called Optical Camera Communications (OCC). Similar to VLC, OCC also operates in visible light spectrum emitted from LED, but OCC uses imaging device (CCD or CMOS image sensor) to receive data instead of photodiode. That's the reason why OCC is known as the extension of VLC in the standardization [3]. In image processing based OCC using commercial camera, has limited data rate up to now, 1 byte-per-second of Casio's demo and 3kbps of PureLiFi's demo [5]. The data rate enhancement is one consideration to promote OCC as one of alternative wireless technology to RF. There is some consideration about capacity of data rate. First of all is about sampling operation and synchronization. The bidirectional OCC with synchronization will be very complex. So it is a challenge to provide uplink. Meanwhile, according to our previous work [2], unidirectional OCC is simple but the effect of exposure time and variation of camera's frame rate is problematic. The longer exposure time is, the more damage effect to communications is by capturing in transient time of bits of transmitter (known as ON-OFF switching time of LED) [1]. Moreover, according to our experiment [1], there a various kinds of camera which has unstable frame rate during recording time. These difficulties will reduce maximum data rate of OCC system. In order to enhance data rate, multi LEDs are used

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*Electronic Engineering, Kookmin University (trang.kmu@gmail.com & namtuanlnt@gmail.com)
**Electronic Engineering, Kookmin University (yjang@kookmin.ac.kr)
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transmitting data simultaneously. However, by this way, the number of LEDs in transmitter should be limited corresponding to the fixed resolution of camera receiver and the size of each LED is also required big enough for considerable far transmission distance.

This paper introduces multi colors encoding and decoding technique for data rate enhancement of image processing based OCC, up to 15kbps achieved and even more. Method of multi-colors On-Off Keying (OOK) modulation in transmitter side together with image processing algorithm in multi LEDs receiver side is proposed to provide better capacity of system. Previously, single color based OOK modulation allows one LED transmit one bit each time [1-2], but by using multi-colors, one LED can transmit more than one bit each time, which improves data rate much. In this paper, three color channels were used, which are Red, Green and Blue channel, to combine and transmit 8 different colors; so one LED could transmit three bits each time. After multi colors data is encoded, how to decode multi colors in real-time while image frames are sequentially coming is given and evaluated.

The paper is organized as follow. Section I gives the introduction of work, followed by section II giving architecture and operation of OCC system. The encoding and decoding technique based on image processing are proposed in section III. Section IV gives some experimental results and implemented work.

Ⅱ. OCC Sytem Operation

In OCC system, LEDs or LCD screen acts as transmitter which requires its own encoding scheme suitable for imaging operation and decoding in the receiver side. And OOK scheme is usually used because of its simplicity. After modulated, encoded data will be transmitted through optical channel to the camera receiver, either global or rolling shutter camera.

A. *Unidirectional OCC*

Based on the requirement of system, OCC may have uplink or not. Some kinds of protocol can be used for uplink, electromagnetic wave such as Bluetooth, WiFi, etc; or light spectrum such as Flash or Ir. The bidirectional OCC (two ways of communications with uplink) is useful, but there is challenging to provide uplink from portable imaging device to LED. Meanwhile, unidirectional OCC is simple and feasible for broadcasting service in the public places for example. The proposed architecture of unidirectional OCC system given below in Fig. 1a (transmitter side) and Fig. 1b (receiver side) is for multi colors transmission.

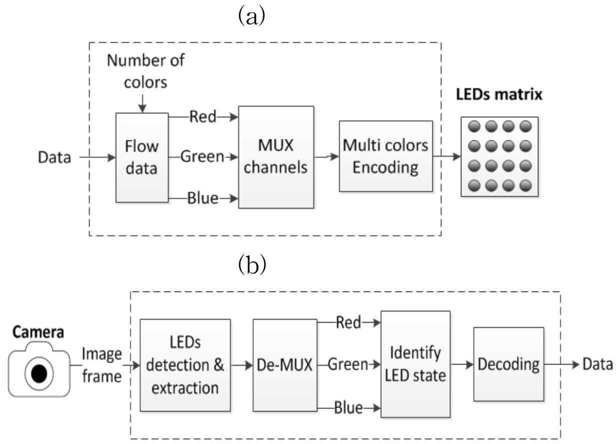

Figure 1. Block diagram of (a) OCC Transmitter and (b) OCC Receiver for multi colors transmission.

In the transmitter side (Fig. 1a), three colors channel Red, Green and Blue are proposed to be used in encoding. The encoding technique will be given in the section right below. In the receiver side (Fig. 1b), there are some main steps to output binary data from each image frame coming. One is the detection and extraction of LEDs' area, or every single LED which is initially necessary for OCC system operation. After detected and extracted, state of every LED (ON or OFF, which color of LED, etc) will be identified. Final is the decoding step using determined state of LEDs.

B. *Asynchronization*

In most of cases, a feedback from receiver to transmitter is to synchronize OCC system. If pulse rate of LEDs is 30pulse per second, equals camera's frame rate, and camera's exposure value is 1/100 s for example, then the accuracy of synchronization required must be smaller than 0.013s to avoid bad sampling [1]. Off course, this accuracy is still not difficulty to implementation; however, based on our experiment, there was another difficult problem must be considered seriously. The statistics of our cameras showed that the frame rate was unstable, normally constant at 31fps but there appeared some valleys of frame rate at above 20fps (see Fig. 2). Then the average value of frame rate was 29.97fps.

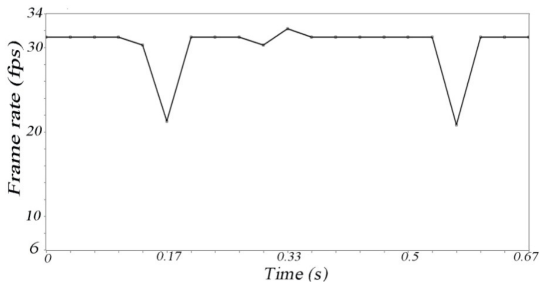

Figure 2. Experimental result of camera's frame rate variation [1]

The variation of camera's frame rate leads to the impossibility of synchronization using uplink in OCC system. Therefore, unidirectional OCC with asynchronous communication scheme is the best way for normal use case of OCC.

Ⅲ. Multi colors transmission

In order to enhance data rate, MIMO system is used. A transmitter consists of many LEDs, and each LED is an independent channel of data transmission. Together with that, multi colors encoding and decoding technique are used based on OOK scheme allowing more than one bit can be transmitted each time will enhance data rate a lot.

A. *Encoding*

The more number of colors is used to encode, the more amount of data rate. For example, we use 3 color elements including Red (R), Green (G) and Blue (B), then their combinations could be 8 different colors including R, G, B, Yellow (=R+G), Pink (=R+B), Purple (=G+B), White (=R+G+B) and Black. Therefore, at the moment of capturing, LED can show one among these 8 colors; thereby LED has ability of transmitting 3 bits rgb. Table 1 and Fig. 2 shows the encoding table and color combination from color R, G and B.

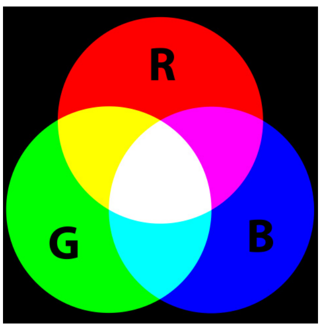

Figure 3. Multi colors encoding diagram

Table 1. Multi colors encoding table

3bits data (rgb)	Encoded color
000	Black
100	Red
010	Green
001	Blue
110	Yellow
101	Pink
011	Purple

Assume that a camera receiver has average frame rate of 30fps (the mean value of camera frame rate while it keep changing); transmitter contains of MxN LEDs; and k bits is transmitted per LED each time. Then, data rate can be calculated as following equation:

Data rate = (30.p). (M.N). k (1)

where:

- (30.p) is bit rate of each LED, which $p \leq 1$ to do over-sampling.
- M.N is the total number of LEDs in transmitter.
- k is number of bits modulated at each LED each time.

As explained in the Operation session previously, the unidirectional OCC is the best option. In operation, the over-sampling together with selection algorithm of image frames [1] are required. And the minimum frame rate of camera receiver (which average value of frame rate is 30fps) must be no smaller than the bit rate of LED transmitter (30.p).

In order to enhance data rate can be proposed as follow: (a) Increase p: The maximum of p is equal to 1, is in case of stable camera frame rate at 30fps and uplink is required to synchronize system. Otherwise, p is smaller than 1 in unidirectional OCC to employ over-sampling. The selection algorithm of frames is optimized to save data rate resource. b) Increase number of LEDs: The more number of LEDs is, the higher data rate is. However, it is limited due to the fixed resolution of image sensor. .(c) Use more colors to encode data: By this way, the physical filter of image sensor together with image processing technique are vital to the maximum color channels achieved. Suppose the Bayer filter is like normal camera (commercial type of camera is used for experiment), encoding table using 8 colors as Table 1 can achieve without big difficulty.

In summary, there are various challenges while implementing. Firstly, p must be much smaller than 1 because camera's frame rate is unstable as proved in Fig. 1 Secondly, the number of LEDs is related to camera's solution and distance between transmitter and receiver, therefore, it is limited. Thirdly, the number of colors must be limited also. At the moment, 3 element colors (R, G and B) are used to mix and create 8 different colors, which allows transmit 3bits each LED each time of transmitting. However, if we use more element colors, camera must have good quality enough to identify different colors, together with accurate and fast algorithm of color detection. As our experiment, one element color (Red for example) will effect to the other element colors (Green and Blue for example) at the same LED, it makes image processing algorithm be more difficult.

B. *Decoding*

OCC system includes a transmitter which controls every color LED displaying, and receiver which camera captures frame by frame to be processed. In the transmitter side, we use LCD screen to display colors instead of using real LEDs. There are 16x16 color LED matrix displayed in LCD screen, or totally 256 LEDs, each LED will be display 8 colors by combining Red, Green and Blue. Pulse rate is constant at 20 pulse/s. Therefore, the achieved data rate is calculated from (1) as follow:

Data rate = 20. 256. 3 = 15360 bps = 15 kbps (2)

In the receiver side, after captured by camera, every image frame will be put in one Queue. One loop will get this Queue status and automatically take frame out to process as an image. This Queue will avoid of missing data, even though processing time sometimes exceeds the requirement of average time of one image frame processing.

1. *LEDs detection and extraction*

M x N LEDs are grouped in square area, surrounded by 4 edges (Fig. 4). So in order to detect LEDs' area, we need to detect 4 edges around them. We propose two solutions of edges detection to extract LEDs.

Solution 1: Search 4 lines to define LEDs' area

By using Line Detection function open library based on Hough transformation [4] which represents one line by couple of parameters (A, r); where A is angle of line, r is distance from coordinate point to the line. Four functions will detect lines by detecting their change of gradient from left to right (Line 1), from right to left (Line 2), from top to bottom (Line 3), or from bottom to top (Line 4) - see Fig. 4.

This solution requires scanning whole image to detect lines, therefore it consumes lots of time and only suitable in powerful processing unit link PC for example, not smartphone. To avoid scanning whole image, user should define Region of Interest (ROI) which containing LEDs' area first, then it is only needed to scan inside of ROI to detect LEDs' area. In smart phone, user often uses one touch action to review auto focus and setup ROI to get focus on interested object. Based on this user's habit, we propose a simpler solution of 4 lines detection. This new solution not only adapts to aim purpose of smart phone App, but also decrease significantly processing time.

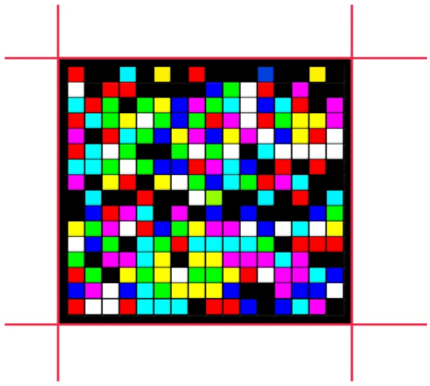

Figure 4. Edges definition for area of LEDs

Solution 2: Search 8 points to define LEDs' area

There are some steps to define edges surrounding LEDs area as follow (see Fig. 5):

- Wait for touch point on screen to define one point inside LEDs' area (Point X1 and X2)
- From first user-defined point (X1), search for 4 points (L1, R1, T1, and B1) by detecting gradient transition.
  L1=Gradient transition from X1 to the left
  R1=Gradient transition from X1 to the right
  T1=Gradient transition from X1 to the top
  B1=Gradient transition from X1 to the bottom
- From second user-defined point (X2), search for 4 points (L2, R2, T2, and B2) by detecting gradient transition.
  L2=Gradient transition from X2 to the left
  R2=Gradient transition from X2 to the right
  T2=Gradient transition from X2 to the top
  B2=Gradient transition from X2 to the bottom
- Define edges of LEDs' area from these 8 points (L1, R1, T1, and B1) and (L2, R2, T2, and B2).

It must be noted that the square area of LEDs may be distorted and becomes quadrilateral when captured from different rotation angle of incoming light with image sensor. LEDs' area is not square or rectangle any more due to incoming angle of light is not perpendicular to image sensor. That's the reason why 8 points are needed to identify LEDs area, not 4 points. Another choice is that there is only one touch point X1 from user definition, then X2 is estimated from X1 and set of (L1, R1, T1, and B1) for identifying set of (L2, R2, T2, and B2).

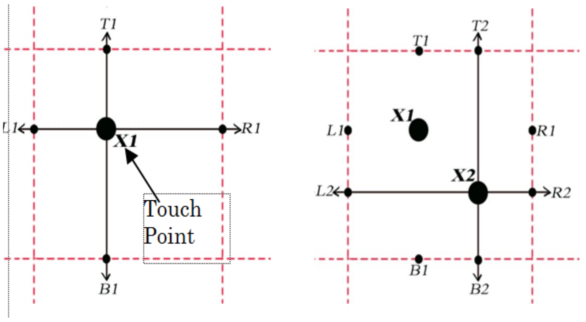

Figure 5. Edges definition from touch points in Smart phone application.

These four edges of LEDs' area should have specific property to identify easily. By setting up the transition of gradient value from inside to outside of LEDs area (black to white – Fig. 4), the change of gradient will help receiver defining points and lines easily. But due to some noise, the detection of some necessary points is missing or wrong, the correction algorithm to recover the edges successfully becomes indispensable.

2. *Color channels De-mux*

The transmitter uses 3 color channels to encode data (Red, Green and Blue), so the intensity images of Red, Green and Blue are used for decoding. Either Bayer image data or color image data can be used to extract the intensity image of red, green or blue channel.

3. ON/OFF Keying Decoding

In order to decode binary data from image, after extracting LEDs' area, states of LEDs can be ON or OFF. The states of LEDs per each image are determined by using pixel value of intensity image (Red, Green and Blue intensity image).

Ⅳ. Result and Discussion

This part presents experimental results of multi colors transmission of OCC based on proposed image processing technique, including color channels testing using camera, and system programming implementation.

A. *Experimental Result*

We do experiment to see which color is the best for transmitting data although the result depends on the Bayer filter. Fig. 6 shows the experimental result of White color transmission, while Fig. 7 shows result of Blue color transmission.

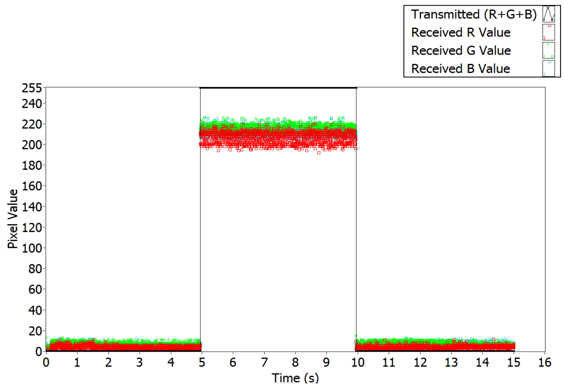

Figure 6. Transmitted White color and received signals in Red/Green/Blue channel

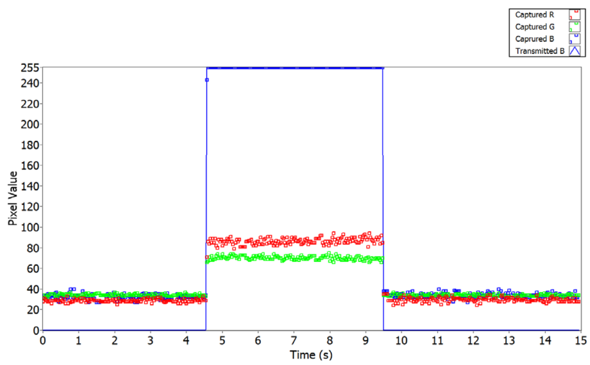

Figure 7. Transmitted Blue color and received signals in Red/Green/Blue channel

Although the result of color transmission and interference between color channels depend on the quality of Bayer filter inside image sensor, the Fig. 6 and Fig. 7 indicate that the interference between color channels is considerable in the use of normal camera sensor. The increasement of the number of color channels (our experiment used 8 colors) is limited due to channels interference.

B. *Software Implementation*

By setting the system as described in Table 2, achieved data rate is computed by:

$$\text{Data rate} = 20.\ 256.\ 3 = 15360 \text{ bps} = 15 \text{ kbps} \quad (3)$$

Table 2. Software Parameters used

Transmitter type	LCD screen
Image sensor	Webcam Samsung SPC-A400M 30fps
Number of LEDs	16x16 LEDs
Size of LEDs' square:	10cmx10cm
Number of colors displaying	8 colors
Distance range	0.5m – 2m
Bit rate per LED	20bps

V. Conclusion

The paper introduced the image processing for Optical Camera Communication. By using multi color encoding and decoding technique, data rate is enhanced a lot. The practical demonstration shows that kbps data rate can be achieved without difficulty using our asynchronous scheme of communication with multi color transmission.

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Authors

Trang Nguyen

Received the diploma degree in School of Electronics and Telecommunications from Hanoi University of Science and Technology, Viet Nam in 2013. Currently, he is pursuing graduate program at Kookmin University. His research interests are Optical Camera Communications and programming.

Nam-Tuan Le

Received the diploma degree in Faculty of information and communication Technology from HaNoi University of Science and Technology, Viet Nam in 2005. He completed his master and doctoral degree in Electronics Engineering from Kookmin University, Korea in 2011 and 2014. His research topics are wireless communication, sensor networks, and visible light communication.

Yeong Min Jang

Received the B.E. and M.E. degrees both in Electronics Engineering from Kyungpook National University, Korea, in 1985 and 1987, respectively. He received the doctoral degree in Computer Science from the University of Massachusetts, USA, in 1999. He worked for ETRI between 1987 and 2000. Since September 2002, he is with the School of Electrical Engineering, Kookmin University, Seoul, Korea. He has organized several conferences such as ICUFN2009, ICUFN2010, ICUFN2011, ICUFN2012, and ICUFN2013. He is currently a member of the IEEE and a life member of KICS (Korean Information and Communications Society). He had been the director of the Ubiquitous IT Convergence Center at Kookmin University since 2005 and the director of LED Convergence Research Center at Kookmin University since 2010. He has served as the executive director of KICS since 2006. He had been the organizing chair of Multi Screen Service Forum of Korea since 2011. He had been the Chair of IEEE 802.15 LED Interest Group (IG-LED). He received the Young Science Award from the Korean Government (2003 - 2006). He had served as the founding chair of KICS Technical Committee on Communications Networks in 2007 and 2008. Currently, he is serving as the Chair of IEEE 802.15.7a optical camera communication study group (OCC SG). His research interests include 5G mobile communications, resource management, small cell networks, visible light communication (VLC), optical camera communication (OCC), and internet of things (IoT).