International Journal of Engineering & Technology, 7 (4.38) (2018) 1399-1401

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

A Study on Optical Camera Communication using Gaussian Window

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Abstract

Optical Camera Communication (OCC) is a Visible Light Communication (VLC) technique using a camera mounted on a digital device as a receiver. Nowadays, most digital devices are equipped with cameras using CMOS Image Sensors (CIS). In this paper, OCC is designed by using Rolling Shutter (RS), which is image output method of CIS. The transmitted data is captured using a camera application built in smartphone, and processed by MATLAB to restore the data. In this paper, we reduce the error rate by performing signal processing using Gaussian Window (GW) on the receiver side without using high-performance camera or directly controlling camera. In addition, we presented the avaliable range of transmission speed of OCC for indoor wireless communication and compared it with throughput in receiver side.

Keywords: *Optical Camera Communication (OCC), Visible light Communication (VLC), Image Sensor Communication (ISC), Indoor communicatioin, Rolling Shutter (RS)*

1. Introduction

Visible Light Communication (VLC) is a next generation wireless communication technique that uses a flickering LED as a transmitter. It overcomes the problem of radio frequency spectrum saturation. Research related to the application of VLC to the mobile environment, and Optical Camera Communication (OCC), using smartphone cameras as receivers, is underway and is gaining attention of the researchers, e.g., IEEE 802.15.7r1 group is currently carrying out research related to the topic. (The IEEE 802.15.7a Study Group)
The OCC is divided into Rolling Shutter (RS) and Global Shutter (GS) depending on the type of camera shutter. RS is the image output mehod of CMOS Image Sensor (CIS). In general, smartphone cameras use CIS.

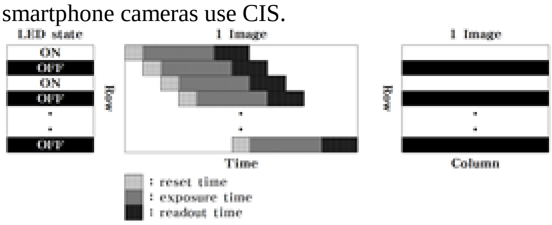

Figure 1. The process of state change of LED output in the image by the Rolling Shutter.

Therefore, many researchers related to OCC for mobile environment use RS. In this paper, we also design OCC system using RS. When transmitting data using the LED, it will blink at an invisible speed. As shown in the Figure 1, the image sensor sequentially outputs an image for each row. There is a time difference that makes bands look like a bar code. The white band corresponds to '1', and the dark band corresponds to '0'. That is why we can communication by using this process of 0's and I's. When capture information by LED using RS, we can contain a lot of bit information in the image

However, RS will lead to some problems, one of which is Inter Symbol Interference (ISI). ISI is a phenomenon of blur between bands in an image taken using RS. Previous studies have solved these problems by increasing the performance of camera direct control and camera itself. (Do, 2015) However, these cause problems of increasing the implementation complexity and cost.
There are two main contribution of this paper. First, we propose a model to improve the communication performance using Gaussian Window (GW).

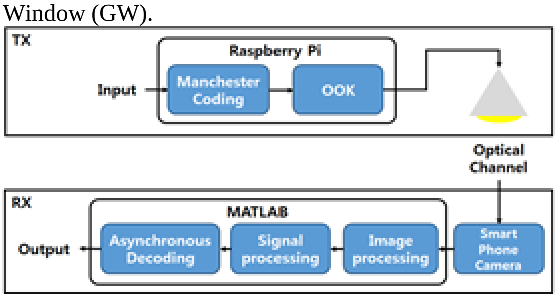

Figure 2. System model of proposed OCC

That is to add signal processing process without directly controlling camera and improving camera specification. Second, we present about avaliable range of transmission speed of the proposed system. Hence, we can see throughput of receiver according to transmission speed in the results.

2. System Model

The proposed system is shown in Figure 2. Transmitter is made in Raspberry-Pi and receiver is the basic camera application in Galaxy Note 3. Various operations and processing are performed in MATLAB. The overall flow of the proposed system is as follows. At the transmitter, the input data is modulated by Manchester coding and packaging as shown in Figure 3. The packet is modu-

lated by OOK for LED control and transmission. At the receiver, the transmitted data is captured by smartphone. At the receiver, the image is taken from the captured video. Next, the image is processed. The signal is extracted from the processed image, and signal processing is performed to remove noise. Finally, asynchronous decoding is performed on the processed signal to extract packet, and data is restored and show in the output.
In the proposed system, we add GW in signal processing to reduce the communication error without high-performance camera or directly controlling. The used signal processing method is GW and shows strong error removal performance. In the below, Transmitter and Receiver are described in more detail.

2-1. Transmitter

In the proposed system, Asynchronous OCC is used to construct communication environment. (Nguyen, 2015)

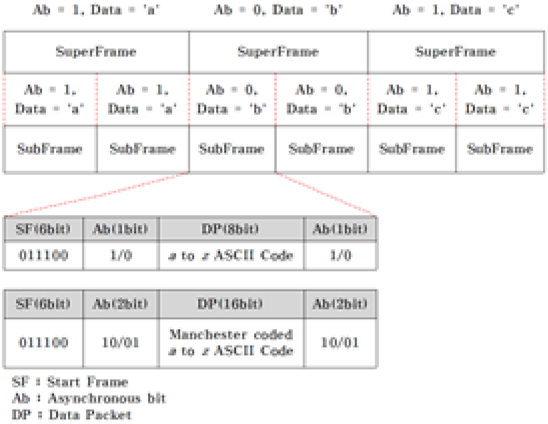

Figure 3. Packet Sturcture of Asynchronous OCC & Example of Data transmission

Figure 3 shows an example of packet structure and data transmission for Asynchronous OCC. The SubFrame consists of a 6-bit Start Frame (SF), a 2-bit Asynchronous bit (Ab), and an 8-bit ASCII Code data packet (DP). In this packet, we assume 3 repeated bit, “111”, In SF in order to calculate the sampling duration at the receiver. However, when a packet transmits withour modulation in transmission, same bit can be repeated in Ab and DP. It makes SF to detect difficulty, the received signal cannot decode. To solve this problem, Ab and DP modulated using Mancchester coding. The input data is transmitted by each SuperFrame. The SuperFrame includes two SubFrames, and each SubFrames in the SuperFrame transmit the same data. The reason for transmitting SubFrame two times is when extracting data from image in receiver, even if the part of received DP in first time is lost the second DP is used for restoring the all data.

2-2. Receiver

There are three steps in the receiver to demodulate information.
First step is the image processing using Histogram Equalization (HistoEQ). One image frame is extracted from the image saved in RGB format and converted into Gray Scale. Next, converted image is processed by using HistoEQ. HistoEQ is an image processing technique that makes the histogram uniform by counting the number of bright pixels and the number of dark pixels in the image. After HistoEQ is applied to image where background is too dark and data is 0, distribution of the dark pixels is dispersed and darker band is visible. In addition, it reduces extinction ratio and improves bit classification performance. (Chow, 2015)

Second is the signal processing. The signal processing stage is a part that restores the original signal from the signal distorted by ISI and noise. For signal processing, we have to change 1280×720 image to a 1×720 array. We call to this as “Signal Extract”. The signal extraction is performed by adding the Grayscale values of all the columns to each row in the image according to Equation 1.

$$S_i = \sum_{j=1} \frac{Gray(i,j)}{1280} \quad i = 1,2,...720\ j = 1,2,...1280 \tag{1}$$

Where in equation 1, the *S* is extracted signal from the image. *Gray* is the HistoEQ image, *i* is row, *j* is column. The horizontal axis of the signal *S* is a row, and the vertical axis is a grayscale value ranging from 0 to 255.

As you can see right side in the figure 4, GW effectively removes noise or ripple, and smoothens the signal. Also, it corrects the width of the signal and improves the bit classification performance.

$$w_G = e^{-\frac{1}{2}\left(\frac{\alpha n}{(N-1)/2}\right)^2} = e^{-\frac{n^2}{2\sigma^2}}, -\frac{N-1}{2} \le n \le \frac{N-1}{2} \tag{2}$$

$$w_G = \frac{w_G}{\sum w_G} \tag{3}$$

$$Y(k) = \sum_i S_i w_G(k - i + 1) \tag{4}$$

Where in Equation 2, *σ* is the standard deviation of the Gaussian random variable and *n* is the window size. As *n* increases, the signal gets smoother. On the other hand, when it becomes smaller, signal becomes sharp. In a slow communication environment, this value does not affect even a little high. However, in the high speed communication environment, since the width of the bit band becomes narrow, an error occurs if *n* becomes large.

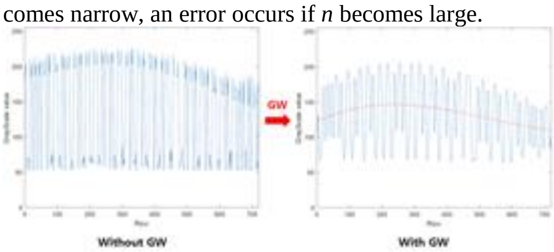

Figure 4. Compare with signal before and after applying GW

n needs to be increased or decreased according to the communication environment. In Equation 3, is a Window Mask with an array following the Gaussian probability distribution. Y in Equation 4 is the noise signal canceled by Window Mask. (Harris, 19778) (Roberts, Richard A.1987) Next, the signal Y is subjected to third order polynomial fitting to obtain a threshold, and a value larger than the threshold is set as 1, and otherwise, it is set to zero. Then, Y become binary signal. (Danakis, 2012)
Binary signal is an array and must be sampled to extract meaningful data. The sampling duration is obtained by SF. In this paper, this sampling duration is called as "Bit resolution". Bit resolution is obtained by dividing by 3 from the length of the interval in which the SF of 1 is repeated in Binary signal. Assuming that the ratio of 1 in the region corresponding to Bit resolution in the binary signal is higher, when the ratio is bigger than 0.5, it is '1'", when it is bigger than 1.5, it is '11' and when it is bigger than 2.5, it is '111'. The sampled signal is a array.
Third step is asynchronous decoding. Extracting packet using asynchronous decoding from the sampled signal, restores DP, and demodulates and outputs recovered data. The reason for using asynchronous decoding in packet extraction is due to Inter Frame Gap (IFG). IFG is a slight time interval between captured images, it is one of the causes of bit data loss in OCC. A camera with a fixed frame rate can estimate the amount of bit data that has disappeared at this interval, but a typical smartphone camera has a variable frame rate and cannot estimate. Therefore, an asynchronous system is required because the transmitter and the receiver cannot be synchronized. Also, since the exacted value of IFG cannot be known, the proposed system uses a method of including one SubFrame in the image. Because, if the length of SubFrame is

too small to be included in the image several times, the entire packet could be lost by IFG.

Table 1. The communication environment and PLR of proposed system

bit resolution (pixel)	SSL(bit)	*M* / SubFrame Length(bit)	*t*(ms) / Tx speed(bps)	*n*	PLR (%)	
					n/a	GW
4	180	10 / 170	100 / 10000	9	100	1.5934
4	180	9 / 154	100 / 10000	9	92.5926	0.0505
5	144	8 / 138	150 / 6667	9	0.6623	0
5	144	7 / 122	150 / 6667	9	0	0
6	120	6 / 106	200 / 5000	13	0	0
7	102	5 / 90	250 / 4000	13	0	0
9	80	4 / 74	300 / 3333	13	0	0
10	72	3 / 58	400 / 2500	13	0	0
15	48	2 / 42	550 / 1818	13	0	0
20	36	1 / 26	800 / 1250	13	0	0

SSL : Sampled Signal Length
M : Number of DP
t : bit transmission duration
n : window size

The asynchronous decoding algorithm was proposed by (Nguyen, 2015). In asynchronous decoding, the data including the lost bit is restored and output by using Ab and SF. In this paper, we use this algorithm to create an environment that can transmit and receive data.

3. Experiments and performance analysis

Table 1 shows the values set in the transmitter and receiver for establishing the communication environment. Also, the result of Packet Lose Rate (PLR) before and after applying GW is shown. First, the communication environment is described. In this experiment, we present 10 communication environments. Bit resolution is used to find the Sampled Signal Length (SSL), and SubFrame length to be transmitted by the transmitter is defined based on this value. SubFrame length is obtained using Equation 5. SF, Ab, and DP are the bit sizes of SF, Ab, and DP, respectively, and M is the number of DPs.

$$SubFrame\ Length = SF + Ab \times 2 + DP \times M \quad (5)$$

$$1 < \frac{SSL}{SubFrame\ Length} < 2 \quad (6)$$

Also, since one SubFrame should be included in the image for asynchronous decoding, each communication environment satisfies Equation 6. t is the bit transmission duration, and Tx speed is $1/t$. These values were obtained through several data transmission experiments based on SubFrame Length and bit resolution. The size of n is set to 9 in 6.667kbps to 10kbps, otherwise it is set to 13. The area where the error can not be eliminated even by using GW is defined as the upper limit of Tx speed. In proposed system, the Tx speed is faster than 10kbps. On the other hand, Lower limit of Tx speed is 1.25kbps, which transmits the minimum unit of packets.

When communication environment is determined by the above conditions, PLR before and after applying the GW is compared. See the part that compares PLR in Table 1, it can be seen that there is no error in the communication environment where the DP length of SubFrame is 7 or less, regardless of GW. However, In 6.67kbps and 10kbps, we can observe after GW, PLR is reduced.

Figure 5 shows the change in Tx speed and Rx throughput after applying GW. As the Tx speed increases, Rx throughput becomes faster.

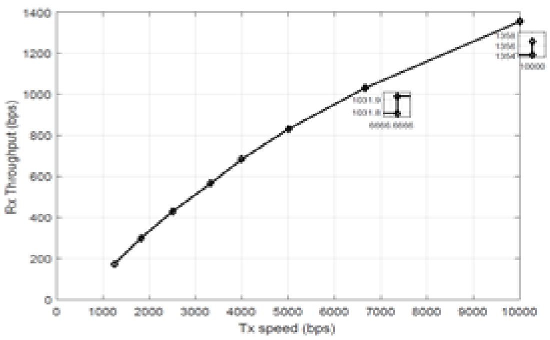

Figure 5. Transmission rates versus Receiver throughput after GW

Also, In 6.67kbps and 10kbps, When M increases, it can be seen Rx throughput is slightly increased. We can see that the overall change in the graph is not linear, as, the change in packet length is based on Equation 5, 6. Another reason is variable frame rate.

4. Conclusion

In this paper, we proposed an improved scheme in OCC using GW, in order to reduce communication error. The introduction of GW reduced the communication error at 6.667kps and 10kbps Tx speed. Also, we tested and verified the possibility of communication and discussed the problems through analysis of data transmission performance using 10 communication environments for the proposed system. Furthermore, the proposed system can be improved through camera control. For the extension of this work we will find more ways to add camera control without increasing the implementation complexity.

Acknowledgements

This research was supported by The Leading Human Resource Training Program of Regional Neo industry through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and future Planning(2016H1D5A1910776).

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