

Elimination of Effect of Heterogeneous Background in Smartphone Visible Light Communications

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ABSTRACT

Much research has been devoted to investigating visible light signal detection using CMOS sensor embedded in smartphone under the scenario of pure white background. However, the characteristics of the reflection surface are not always homogeneous in a practical environment. This study proposed a background-subtraction-like image processing for visible light signal detection under a heterogeneous background. Experimental results demonstrated that the proposed method achieved the same bit error rate and packet error rate performance no matter under the homogeneous background or the heterogeneous background.

INTRODUCTION

In recent years, light emitting diode (LED) lamps have become more and more popular, serving a foundation for development of visible light communications (VLC) to be a promising candidate to effectively solve the problem of radio frequency spectrum shortage in the next generation of wireless communication systems. Unlike the disadvantages of exist of electromagnetic interference (EMI) in radio communications, VLC is EMI free and suitable for applications in EMI-sensitive environments like aircraft cabins and hospitals [1]-[2]. In this paper, the scenario of a non-line-of-sight (NLOS) VLC that adopts LED and image sensor embedded in smartphone as transmitter and receiver, respectively, is considered.

In the literature, the method of polynomial fitting was mainly used to mitigate the effect of the blooming effect caused by the rolling shutter. However, most results reported in the literature were on the condition that the smartphone receives light signal reflected from a pure white background. Performance was severely degraded when smartphone camera receives the reflected light from low reflective color [3]. In this paper, a new signal detection method will be presented to eliminate the effect of low reflective color for NLOS light-camera VLC.

OPERATING PRINCIPLE

Light-camera VLC is consider being beneficial to promotion of VLC owing to the digital camera has become a default device in smartphone nowadays. Due to the rolling shutter effect, there are bright and dark fringes on an image frame when the VLC transmission rate is higher than the image frame rate. To demodulate the bright and dark fringes into their original logic bits, the image can be converted into grayscale format, in which each pixel value is represented from 0 to 255 grayscale levels. In practice, the gray values between 0 and 255 exist on an image frame because of the blooming ef-

fect and the exposure time of each row are overlapping. A column vector of gray values on the image frame should be carefully selected to possibly mitigate the blooming effect for signal demodulation [1]-[2]. Polynomial fitting was applied to the selected column vector of gray values for the construction of decision threshold. Finally, the data signal can be decided to be logic 0 when the selected gray value is larger than the threshold value while the logic signal can be detected to be logic 1 when the selected gray value is smaller than the threshold value.

THE PROPOSED DETECTION ALGORITHM

The signal demodulation method mentioned in the previous section was successfully demonstrated under pure white background in the literature. However, the background is not always white in a practical environment. In a practical environment, a bright surface causes strong reflection while a dull material appears less reflection. This phenomenon aggravates the blooming effect, resulting a severe performance degradation of the signal demodulation method mentioned in the previous section. Because the heterogeneous background causes noise to the image, it is motivated to adopt image background subtraction for image denoising.

In the background subtraction (BS) scheme, the foreground objection is detecting by the difference between the current image frame and a background frame, often called "reference image". Traditionally, the first image frame captured by camera is used as reference frame. In our proposed BS-like method as shown in Fig. 1, a pure black frame is adopted to be the background frame since the pure black background is rare in the practical environment, and hence it is beneficial to keep the bright and dark fringes in foreground by subtracting this pure black frame from the current frame. To reduce the gray level image to a binary image, the threshold T is calculated by using Otsu's method [4].

In Fig. 1, it is shown that there are still some image noises in the detected bright and dark fringes. To further reduce these image noises, the pixel values in each row are averaged as shown in Fig. 2 (a). Subsequently, a second-order polynomial fitting is applied to the averaged row pixel values. By comparing the averaged row pixel value and the polynomial fitting curve, the bright and dark fringes can be retrieved as shown in Fig. 2 (b).

EXPERIMENT, RESULTS AND DISCUSSION

A. Experimental Setup

The pseudo-random binary sequence (PRBS) is generated in LabVIEW and is connected to an arbitrary function generator (Tektronix AFG3151C) using the LabVIEW environment, which then mixed with the DC bias current priori to intensity modulation of the white light LED (EXCEED RL-PC38WC1).

The distance between a heterogeneous background and the smartphone is 30 cm. By taking video, the reflected white light from the heterogeneous background is perceived by the embedded CMOS sensor of the ASUS Zenfone 3 smartphone (ZE552KL), which is set with 3200 ISO and 1/5000 exposure time. Subsequently, the taken video is processed using open source computer vision library (OpenCV) in C++ implementation.

B. Results

The PRBS is packetized as the combination of a 7-bits packet preamble and two data blocks as shown in Fig. 3. Each data block contains of an 8-bits Manchester coding header and 20 data bits with on-off keying modulation as shown in Fig. 4. Fig. 3 shows the experimental results of the proposed signal detection method under a heterogeneous background. In Fig. 5, the bit error rate (BER) of the proposed method is approximately 2.6×10^{-3} while the BER of the original method is around 1.7×10^{-1} . Fig. 6, presents the packet error rate (PER) of the proposed signal detection method under a heterogeneous background. In Fig. 6, the PER of the proposed method obviously outperforms the original method.

CONCLUSIONS

This paper has presented a new signal detection method for a NLOS VLC using CMOS sensor embedded in smartphone under a heterogeneous background. Image noise caused by a heterogeneous background had be eliminated by the proposed BS-like image preprocessing, and hence resulting in a clearer bright and dark fringes and achieving better BER and PER. Experiments similar to those reported here should be conducted using a wider variety of scenarios.

REFERENCES

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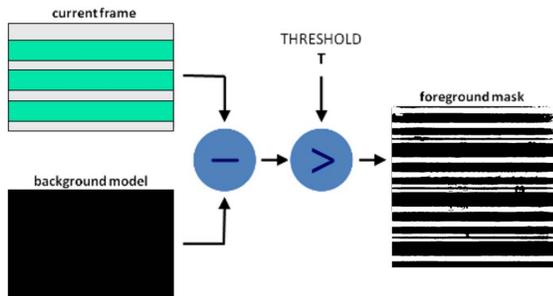


Fig. 1 The proposed BS-like image preprocessing.

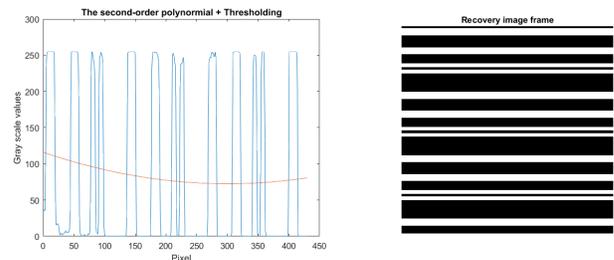


Fig. 2 (a) Row averaged and second-order polynomial fitting (b) Recovery image frame

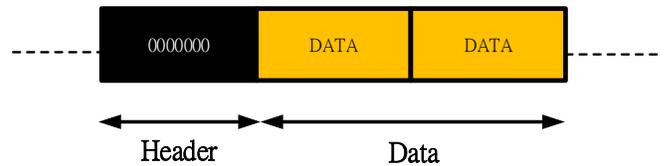


Fig. 3 The format of the transmission packet.

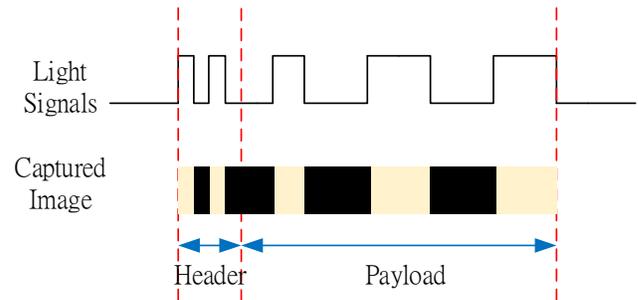


Fig. 4 The format of the data block.

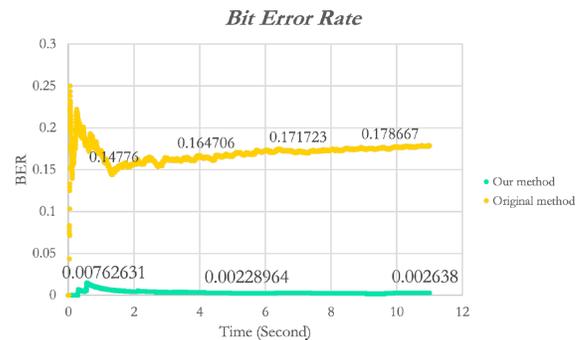


Fig. 5 The bit error rate versus the number of the video frames

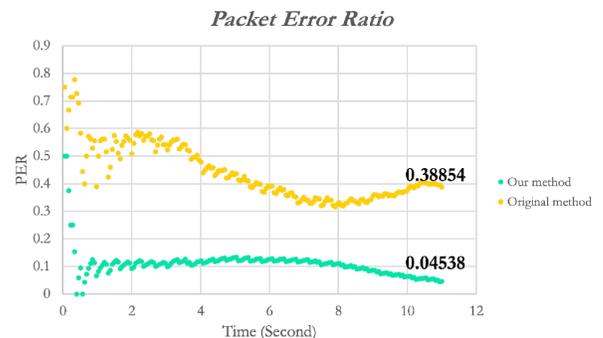


Fig. 6 The packet error rate versus the number of the video frames