

Preventing Degradation of the Quality of Visual Information in Digital Signage and Image-Sensor-Based Visible Light Communication Systems

Volume 10, Number 3, June 2018

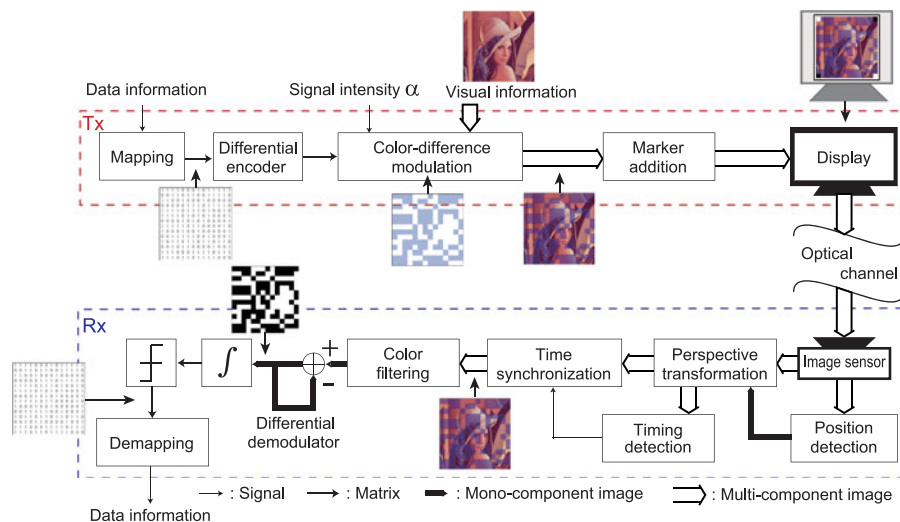
Hiraku Okada, *Member, IEEE*

Sho Sato

Tadahiro Wada, *Member, IEEE*

Kentaro Kobayashi, *Member, IEEE*

Masaaki Katayama, *Senior Member, IEEE*



DOI: 10.1109/JPHOT.2018.2829146

1943-0655 © 2018 IEEE

Preventing Degradation of the Quality of Visual Information in Digital Signage and Image-Sensor-Based Visible Light Communication Systems

Hiraku Okada ¹, Member, IEEE, Sho Sato,¹
Tadahiro Wada ², Member, IEEE,
Kentaro Kobayashi ¹, Member, IEEE,
and Masaaki Katayama ¹, Senior Member, IEEE

¹Nagoya University, Nagoya 464-8603, Japan

²Shizuoka University, Hamamatsu 432-8561, Japan

DOI:10.1109/JPHOT.2018.2829146

1943-0655 © 2018 IEEE. Translations and content mining are permitted for academic research only.

Personal use is also permitted, but republication/redistribution requires IEEE permission.

See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.

Manuscript received February 20, 2018; revised April 10, 2018; accepted April 17, 2018. Date of publication April 23, 2018; date of current version May 14, 2018. This work was supported by JSPS KAKENHI under Grant 16K06348. Corresponding author: Hiraku Okada (e-mail: okada@nuee.nagoya-u.ac.jp).

Abstract: In this paper, we propose an image-sensor-based visible light communication (IS-VLC) system that provides visual information in digital signage used for advertisements. One important issue of IS-VLC systems is the deterioration of visual information while transmitting the data information. Human eyes are sensitive to luminance but not to color difference; therefore, we propose the modulation of color difference. We evaluate the performance of the proposed system in terms of both the quality of visual information and communication quality of data information, and clarify the effectiveness of the proposed system.

Index Terms: Digital signage, image sensor, visible light communication, YCrCb color space.

1. Introduction

Digital signage attracts much attention because of its advantages over conventional advertisements. For example, digital signage can provide dynamic visual advertisements which have high flexibility through the introduction of time-based advertisement space. Nowadays, digital signage is not only used for advertisements (visual information) but also for information dissemination systems. Some applications using digital signage are proposed, e.g. providing multilingual information of visual information for foreigner and distribution of emergency information in disaster [1], [2]. These applications require a data rate of about one or several kbps. Thus, the addition of the function of providing data information to digital signage is desirable.

In this paper, we employ an image-sensor-based visible light communication (IS-VLC) system [3], [4] to provide data information. In such a system, a display of digital signage and the image sensor (camera) of a smartphone are used as a transmitter and as a receiver, respectively. The display presents visual content containing both visual and data information. The smartphone's image sensor captures the visual contents and derives the corresponding data information. This IS-VLC system does not need the introduction of extra devices. In addition, the linking data information

to visual information is possible. Such collaboration will bring about an innovation in advertising. One important issue of the IS-VLC system is the deterioration of visual information while data information is being transmitted. The display provides visual contents, but the IS-VLC system must not hinder the visual information.

In this paper, we propose an IS-VLC system in which the deterioration of the quality of the visual information cannot be perceived by human eyes. We focus on the color differences of the YCrCb color space because human eyes are sensitive to luminance but not to color differences. The YCrCb color space consists of luminance (Y), red color difference (Cr), and blue color difference (Cb). We performed a preliminary evaluation of the proposed system [5], but the data transmission by the Cb component was only evaluated from the viewpoint of communication quality. The performance of the Cb component was not compared to those of other color components, such as red (R), green (G), blue (B), Y, and Cr. In addition, the proposed system is required to maintain the quality of visual information. The quality of visual information and the communication quality of data information are considered herein to evaluate the performance of the proposed system.

2. Related Work

One of the characteristics of the human eyes is its insensitivity to gradual changes in visual contents. In [6], data information was transmitted using markers whose colors gradually change. This system can be realized by a conventional display and image sensors. The markers are embedded in the visual information whereas data information can be retrieved from images captured via the image sensors. However, the data rate is approximately 10 bps. In [7], the visual information was divided into rectangular regions and the data information was transmitted by slightly changing the luminance component of each region.

The time frequency bandwidth of human eyes is limited to approximately several hundred Hz. In [8], [9], the digital signage transmits data information by modulating backlight of a display at several kHz. Using a rolling shutter effect with the CMOS image sensors, data information is demodulated from images captured by a smartphone. This system achieves a higher data rate of approximately 1 kbps. However, this system requires a special display to modulate its backlight.

In this paper, we use the insensitivity of human eyes to determine the color difference. This method does not require a gradual change in the visual components and aids in improving the data rate. In addition, the proposed system can be implemented by conventional display and image sensors.

3. Proposed IS-VLC System Using Color Difference Modulation

To avoid the deterioration of visual information, we propose a perceptually difficult IS-VLC system using a color-difference modulation on a YCrCb color space. A color space is a space representing a color with bases. The well-known RGB color space consists of R, G, and B components, and these components include not only color but also luminance. In contrast, the components, Cr and Cb, in a YCrCb color space do not include luminance, as shown in Fig. 1. As described in Section 1, human eyes are sensitive to luminance but insensitive to color difference. Based on this insensitivity, we embed data information in the color-difference components, Cr and Cb, of visual contents while keeping the luminance component, making the embedding of the data information possible while avoiding the deterioration of the quality of the visual contents.

Fig. 2 shows a block diagram of the proposed IS-VLC system. In the transmitter of the display, data information is mapped onto a matrix, which is differentially encoded. In our system, to remove the visual information, the receiver subtracts successive received images. When a differential encoder is used at the transmitter, the receiver can demodulate and decode the data information by the subtraction of the successive received images. Therefore, a differential encode is used at the transmitter. The encoded data is modulated on a color-difference component of the visual content; then, the modulated image is shown on the display. A receiver (e.g., a smartphone) captures the modulated image with its image sensor. After detecting the position and timing, the visual information of

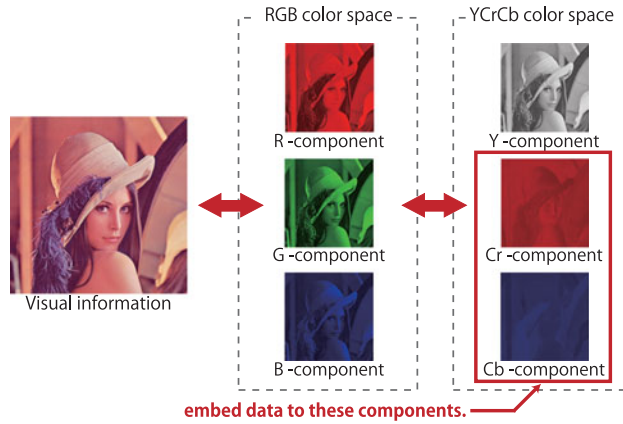


Fig. 1. RGB and YCrCb color spaces.

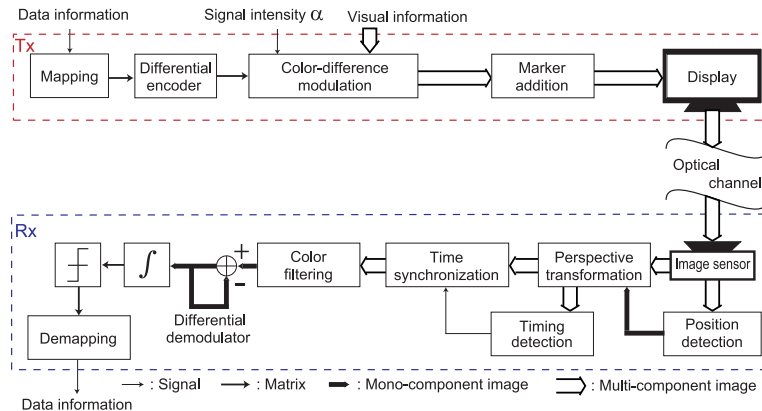


Fig. 2. A block diagram of the proposed IS-VLC system.

the captured image is removed by subtracting the successive images followed by the demodulation of data information. The details of the proposed system are explained in the following sections.

The notations used in this paper are defined as follows. A multi-component (color) and mono-component image are expressed by \mathcal{I} and \mathbb{I} , respectively. The pixel at (x, y) of an image \mathbb{I} with width X and height Y is expressed as $\mathbb{I}_{(x,y)}$. The element of the n th row and the m th column of the $N \times M$ matrix, \mathbf{A} , is denoted as \mathbf{A}_{nm} . A color component of an image is represented by superscripts. For example, \mathcal{I}^{Cb} means the Cb components of the image \mathcal{I} .

3.1 Transmitter

First, data information is mapped onto a data matrix, where $\mathbf{D}(i)$ indicates the i th data matrix which has N rows and M columns. The data matrix is differentially encoded to obtain the coded data matrix $\mathbf{C}(i)$. In the color-difference modulation, a mono-component data image $\mathbb{C}(i)$ is generated from the coded data matrix, as shown in Fig. 3, where α is signal intensity. Then, the data image is added to the color-difference components of the visual information. Let $\mathcal{V}(i)$ be an image containing the visual information. When the data information is embedded into the Cb components, an image after the color-difference modulation is expressed by

$$\mathcal{T}(i) = \begin{bmatrix} \mathcal{T}^{\text{Y}}(i) \\ \mathcal{T}^{\text{Cr}}(i) \\ \mathcal{T}^{\text{Cb}}(i) \end{bmatrix} = \begin{bmatrix} \mathcal{V}^{\text{Y}}(i) \\ \mathcal{V}^{\text{Cr}}(i) \\ \mathcal{V}^{\text{Cb}}(i) \end{bmatrix} + \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{C}(i) \end{bmatrix}. \quad (1)$$

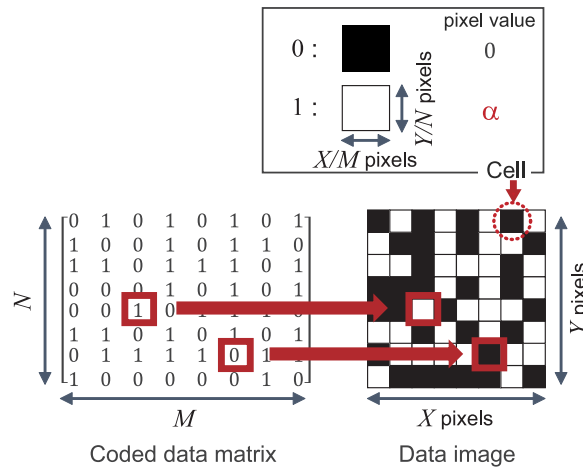


Fig. 3. Relationship between data matrix and data image.

The marker is added to the modulated image, and a transmission image is created. We focus on the proposal and evaluation of the IS-VLC system using the color-difference modulation and use a simple method to detect the position of the modulated image and synchronize the timing at the receiver. A rectangular frame is used as a position detection marker and the blinking rectangular markers are arranged at the four corners for the time synchronization marker [5]. The markers are attached to the transmission image, which is shown on the display.

3.2 Receiver

The image sensor of the receiver captures the modulated image on the display. Using the rectangular frame, the position of the transmission image is detected, only the transmission image is extracted, and shaped into a rectangle by perspective transformation. Using the blinking rectangular markers, the timing of the transmission image is detected and only the synchronized received image is derived. The details of the above procedure are explained in [5], [10]. After color filtering of the embedded color component, the mono-component received image $\mathbb{R}(i)$ is derived. The received image is expressed by

$$\mathbb{R}(i) = \mathcal{V}^{\text{Cb}}(i) + \mathbb{C}(i) + \mathbb{N}(i), \quad (2)$$

where $\mathcal{N}(i)$ represents noise and inter-cell interference caused by incomplete position detection.

Now, we assume the visual information to consist of either still or almost still images. Since the data matrix is differentially encoded, the data image can be retrieved by subtracting successive received images as follows:

$$\begin{aligned} \hat{\mathbb{D}}(i) &= \mathbb{R}(i) - \mathbb{R}(i-1) \\ &= \left\{ \mathcal{V}^{\text{Cb}}(i) - \mathcal{V}^{\text{Cb}}(i-1) \right\} + \left\{ \mathbb{C}(i) - \mathbb{C}(i-1) \right\} + \left\{ \mathbb{N}(i) - \mathbb{N}(i-1) \right\} \\ &= \mathbb{D}(i) + \mathbb{N}'(i), \end{aligned} \quad (3)$$

where $\mathbb{N}'(i)$ includes the residual of the subtraction of the visual images. Even in the case of moving images, significant suppression of the components of the visual information can be expected, unless a scene change occurs. The pixel values included in each cell of the retrieved data image are integrated. The matrix after integration is expressed by

$$\tilde{\mathbb{D}}_{jk}(i) = \sum_{x \in C_x(j)} \sum_{y \in C_y(k)} \hat{\mathbb{D}}_{(x,y)}(i), \quad (4)$$

TABLE 1
A Display Datasheet

LCD type	47 inch, TTL LCD
Resolution	1920 × 1080
Brightness	450 cd/m ²
Size of LCD	w:1039.7 mm × h:584.8 mm
Refresh rate	60 Hz

TABLE 2
Raspberry Pi Camera Module v1 Datasheet

Image sensor	Omnivision 5647 CMOS image sensor, a fixed-focus module with integral IR filter
Resolution	5 Mpixels
Max image transfer rate	1080p: 30 fps
Lens size	1/4
Dimensions	20 mm × 25 mm × 10 mm

where $C_x(j)$ and $C_y(k)$ indicate the set of pixel numbers for the (i, j) elements of the data matrix. The data matrix $\hat{\mathbf{D}}(i)$ is retrieved from the matrix $\tilde{\mathbf{D}}$ by a threshold decision. Finally, we can derive the data information by demapping the retrieved data matrix.

4. Experimental Evaluation

Digital signage must maintain the quality of visual information even if data information is transmitted by the IS-VLC system. It is important to evaluate the proposed IS-VLC system in terms of not only the communication quality of the data information but also the quality of the visual information. In this paper, a bit error rate is derived as a parameter of a signal intensity via a data transmission experiment to evaluate the communication quality. Meanwhile, the evaluation methods of the quality of the visual information are diverse, so an appropriate method must be selected.

The methods for the quality evaluation of visual information are roughly divided into two classes: objective and subjective evaluation. In objective evaluation, the peak signal to noise ratio (PSNR) [11] and structural similarity (SSIM) [12] are well known. In contrast, in subjective evaluation, the quality of visual information is measured using evaluators. This method requires much effort but is reliable because it is directly based on the human eyes. As subjective evaluation, absolute category rating (ACR) [13] and double stimulus continuous quality scale (DSCQS) [14] are known. In this paper, we employ ACR, and evaluate the quality of visual information as a parameter of a signal intensity.

The signal intensity is only a parameter of the color-difference modulation, and the impact of the signal intensity will be different for each color component. Therefore, we compare the bit error rate of each color component based on the quality of the visual information from the experimental results of the data transmission and the quality evaluation of visual information.

4.1 Experimental Environment

For the simplification of the system implementation, we assume a fixed display and an image sensor with visual information as still images. A tripod was used to position the image sensor at almost the same height as that of the display. In addition, to eliminate the influence of the computing resources of the receiver, we processed the demodulation offline. The transmitter consisted of a computer and an LCD display. The receiver was composed of a Raspberry Pi Model B with a Raspberry Pi camera v1 module. The datasheets of the display and the image sensor are shown in Tables 1 and 2, respectively.



Fig. 4. Images of visual information. (a) Autumn. (b) Gerbera. (c) Lake.

TABLE 3
Settings for the Data Transmission Experiment

Transmitting image rate	5 fps
Capture frame rate	10 fps
Resolution of transmitting image	1920 pixels \times 1080 pixels
Cell construction (M, N)	(19, 10)
Resolution of capture image	1920 pixels \times 1080 pixels
Distance between a display and a camera	3.30 m (5.6 H)
Signal intensity α	1, 2, 3, 4, 5
Embedding components	R, G, B, Y, Cr, Cb
Visual information	Autumn, Gerbera, Lake

As visual information, we used three images, Autumn, Gerbera, and Lake, which are shown in Fig. 4. Autumn exhibits high space frequency and high overall luminance. Gerbera exhibits low space frequency, low overall luminance, and red as the dominant color, whereas Lake exhibits low space frequency, high overall luminance, and blue as the dominant color. The pixel values of these images were clipped to avoid the saturation of the values when the data information was embedded.

4.2 Data Transmission Experiment

The settings for the data transmission experiment are shown in Table 3. The typical capture frame rate of the image sensor is approximately 30 fps. In this experiment, since we focus on the evaluation of the communication quality of the proposed system, the capture frame rate was set at 10 fps to suppress the degradation that occurred because of synchronization deviation. The transmission image rate was set at 5 fps, which was half of the image sensor's capture frame rate.

The resolutions of the transmission images were 1080 p full HD, whereas the pixels of $X = 1920$ and $Y = 1080$ were divided into 190 cells, where $M = 19$ and $N = 10$. The cells at the four corners of the transmission image were used as markers for time synchronization. Each marker and its adjacent two cells, comprising a total of 12 cells for all the markers, were excluded from the evaluation of the bit error rate. The number of cells evaluated was 178 cells per image, and the transmission data rate was 890 bps. The image sensor also used 1080 p full HD. The distance between the display and the image sensor was set at 3.3 m, i.e., the viewing distance was about 5.6 H. Signal intensity α was set at $1 \leq \alpha \leq 5$, where the pixel values of an image were from 0 to 255.

4.3 Experiment for Quality Evaluation of Visual Information

In this paper, we used the ACR method to evaluate the quality of the visual information. After watching the visual information, the evaluators scored it from 1 to 5. The quality is then expressed as a mean opinion score (MOS), which is the average value of the scores. The experiment environments and parameter settings were the same as those of the data transmission experiment. The evaluators consisted of 23 males and 13 females.

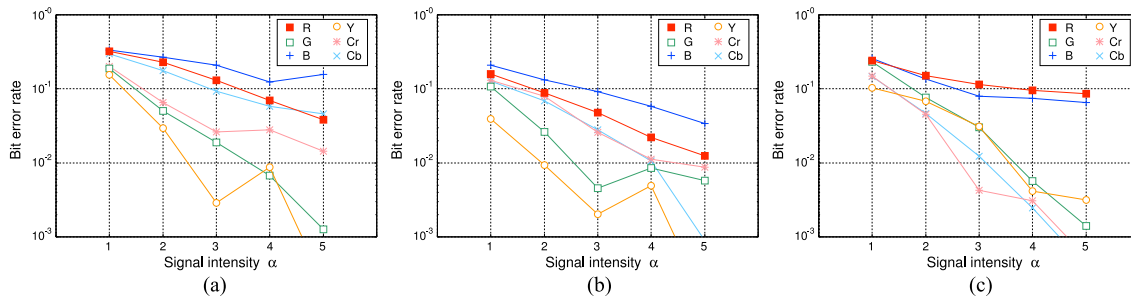


Fig. 5. Bit error rate performance as a parameter of signal intensity α . (a) Autumn. (b) Gerbera. (c) Lake.

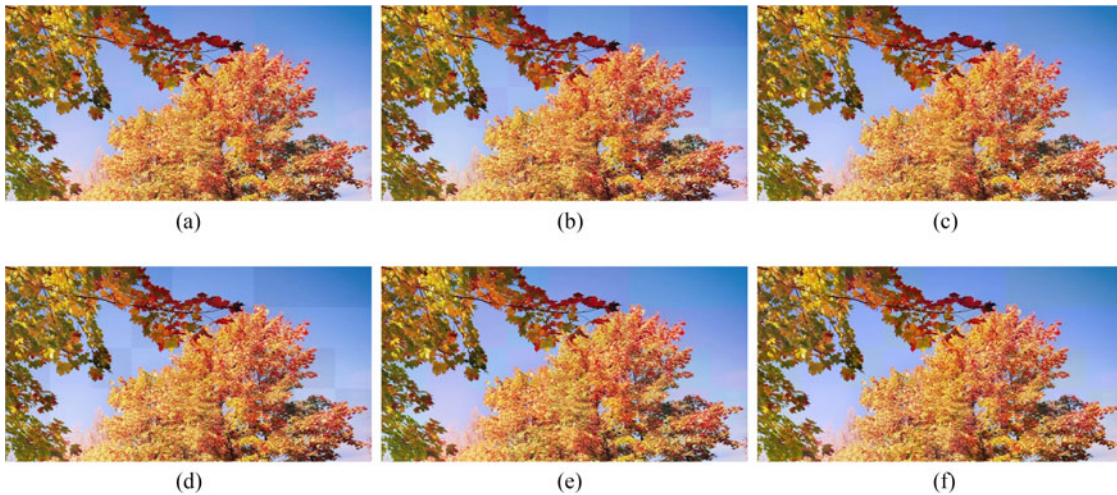


Fig. 6. Examples of transmission images ($\alpha = 5$). (a) Autumn (R). (b) Autumn (G). (c) Autumn (B). (d) Autumn (Y). (e) Autumn (Cr). (f) Autumn (Cb).

4.4 Experimental Results

Fig. 5 shows the bit error rate in the data transmission experiment. The bit error rate improves as the signal intensity α increases. Note that the bit error rates depend on the color components even if the signal intensity is the same. In addition, the bit error rates are affected by the visual image. This phenomenon is caused by the mismatch of color balances between the display of the transmitter and the image sensor of the receiver.

Some examples of the transmission images are shown in Fig. 6, where signal intensity is set by $\alpha = 5$. In these examples, we can confirm the degradation of the visual information for G, Y, and Cr components. To investigate the impact on the visual information, the results of the quality evaluation of the visual information are shown in Fig. 7. The error bars indicate a confidence interval of 95%. Even at the same signal intensity α , we can confirm significant differences in MOS among the components. MOS values are not decided only by the signal intensity. In particular, significant differences are confirmed among the RGB components. If PSNR is used and the signal strength is identical, the same value is obtained for each RGB component. Then, the subjective quality evaluation is required to evaluate the quality of the visual information.

Finally, Fig. 8 shows the bit error rate performance versus the MOS values; therefore, the bit error rate of the same quality of visual information can be evaluated. At $MOS = 4.0$, the best communication quality is achieved by embedding data information on the color-difference components, Cb and Cr, for any corresponding visual information. Here, $MOS = 4.0$ means that about 95% of the evaluators evaluated the quality as “3: normal” or higher. The realization of data transmissions

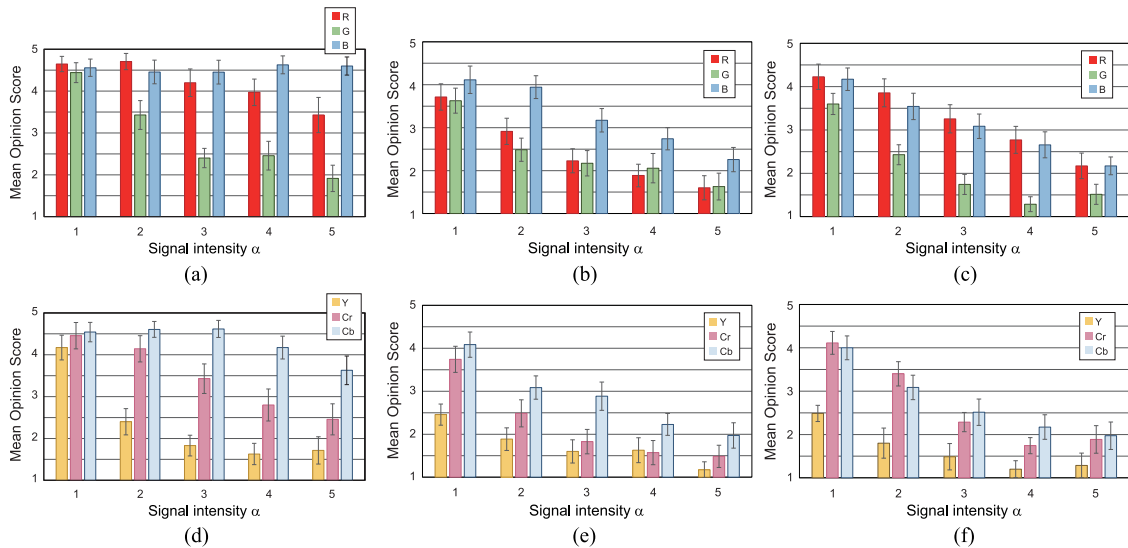


Fig. 7. MOS values as a parameter of signal intensity α . (a) Autumn (RGB). (b) Gerbera (RGB). (c) Lake (RGB). (d) Autumn (YCrCb). (e) Gerbera (YCrCb). (f) Lake (YCrCb).

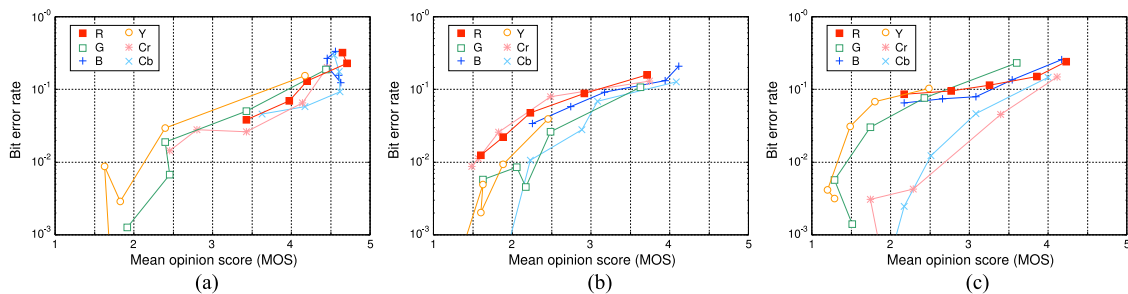


Fig. 8. Bit error rate performance versus MOS values. (a) Autumn. (b) Gerbera. (c) Lake.

by introducing error correction codes, even if the bit error rate is about 10^{-1} , has been reported to be possible [15]. Therefore, the proposed system can transmit the data information by using an error correction code. According to this result, the Cb and Cr components, which do not contain the luminance component, are suitable for embedding the data information. Which of the Cr and Cb components achieves a lower bit error rate depends on the visual information. For Autumn and Gerbera, the bit error rate of the Cb component is lower than that of the Cr component, whereas the bit error rate of the Cr component is lower for Lake.

5. Conclusion

In this paper, we have proposed a color-difference modulation in an IS-VLC system so that the human eyes cannot perceive the deterioration in the quality of visual information when data information is embedded. We have also constructed the system and experimentally evaluated its performance with the ACR method in terms of the bit error rate as well as the quality of visual information. We have confirmed that the color-difference modulation achieves a lower bit error rate compared to the other color components under the condition that the quality of visual information remains the same. Therefore, the proposed system is proven to be useful for digital signage in IS-VLC systems.

This paper focuses on the proposal of the IS-VLC system preventing degradation of the quality of visual information. To avoid synchronization deviation, we employed a low capture frame rate of 10 fps in Section 4. As a result, the transmission data rate of the proposed system was 890 bps.

If the synchronization deviation can be compensated, the data rate of the proposed system is improved. Then, the transmission data rate of one or several kbps will be accomplished.

Acknowledgment

The authors would like to thank Prof. T. Yamazato of Nagoya University for his valuable suggestions.

References

- [1] T. Ogi, K. Ito, and S. Konita, "Multilingual digital signage using iBeacon communication," in *Proc. Int. Conf. Netw. Based Inf. Syst.*, 2016, pp. 387–392.
- [2] M. Y. Huh, W. Hyun, S. H. Kim, and S. G. Kang, "Design of disaster alerting functionality for digital signage service," in *Proc. Int. Conf. Adv. Commun. Technol.*, 2014, pp. 618–621.
- [3] T. Yamazato and S. Haruyama, "Image sensor based visible light communication and its application to pose, position, and range estimations," *IEICE Trans. Commun.*, vol. E97-B, no. 9, pp. 1759–1765, Sep. 2014.
- [4] C. Danakis, M. Afgani, G. Povey, I. Underwood, and H. Haas, "Using a CMOS camera sensor for visible light communication," in *Proc. IEEE GLOBECOM Workshop*, 2012, pp. 1244–1248.
- [5] S. Sato, H. Okada, K. Kobayashi, T. Yamazato, and M. Katayama, "Visible light communication systems using blue color difference modulation for digital signage," in *Proc. IEEE Int. Symp. Personal, Indoor Mobile Radio Commun.*, 2016, pp. 1242–1247.
- [6] K. Kuraki, K. Kato, and S. Nakagata, "File transfer system by a hidden id signaling using camera in smart devices: Easy file sharing between computers and smart devices," in *Proc. IEEE Int. Colloquium Signal Process. Appl.*, 2016, pp. 130–134.
- [7] R. Boubezari, H. L. Minh, Z. Ghassemlooy, and A. Bouridane, "Novel detection technique for smartphone to smartphone visible light communications," in *Proc. Int. Symp. Commun. Syst., Netw. Digit. Signal Process.*, 2016.
- [8] H. Aoyama and M. Oshima, "Visible light communication using a conventional image sensor," in *Proc. IEEE Consum. Commun. Netw. Conf.*, 2015, pp. 103–108.
- [9] C. W. Chow *et al.*, "Secure mobile-phone based visible light communications with different noise-ratio light-panel," *IEEE Photon. J.*, vol. 10, no. 2, Apr. 2018, Art. no. 7902806. doi: 10.1109/JPHOT.2018.2807582.
- [10] J. Amano, T. Wada, and K. Mukumoto, "Construction and evaluation of a parallel transmission image-sensor visible light communication system," *IEICE Trans. Commun.*, vol. J96-B, no. 7, pp. 742–752, Jul. 2013.
- [11] Q. Huynh-Thu and M. Ghanbari, "Scope of validity of PSNR in image/video quality assessment," *Electron. Lett.*, vol. 44, no. 13, pp. 800–801, Jun. 2008.
- [12] Z. Wang, A. C. Bovik, and E. P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," *IEEE Trans. Image Process.*, vol. 13, no. 4, pp. 600–612, Apr. 2004.
- [13] *Subjective Video Quality Assessment Methods for Multimedia Applications*, Rec. ITU-T P.910, Apr. 2008.
- [14] M. Pinson and S. Wolf, "Comparing subjective video quality testing methodologies," *Proc. SPIE, VCIP*, vol. 5150, pp. 573–582, 2003.
- [15] A. Alvarado, E. Agrell, R. Maher, and P. Bayvel, "Replacing the soft-decision FEC limit paradigm in the design of optical communication systems," *J. Lightw. Technol.*, vol. 33, no. 20, pp. 4338–4352, Oct. 2015.