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Watermarking Technique for Images Captured with Cameras Using Color–Difference-Modulated Light

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Abstract— **We propose a new optically written watermarking technique that can protect the portrait rights of real objects. It produces a watermarking pattern in the illumination light by modulating color differences. The illumination light that contains such watermarking is projected onto an object. An image of the object taken by a camera contains the same watermarking, which can be extracted by image processing. Therefore, this technique can protect the portrait rights of real objects. We discovered three findings through simulation where binary data were embedded as watermarking and we evaluated the accuracy with which the binary data were read out. The first was that the accuracy when color differences were modulated was higher than that when brightness was modulated. The second was that errors in reading out embedded binary data particularly tended to occur in dark areas, yellow areas, and areas that contained fine textures. The third was that we could satisfy both the invisibility and readability requirements of embedded data by using appropriate amplitudes of modulation.**

Keywords-Watermarking patterns; information embedding; portrait rights.

I. INTRODUCTION

We recently proposed a digital watermarking technique that used illumination light whose color differences were modulated as a technique to embed information in a captured image of a real object [1] and we demonstrated its feasibility. This paper presents the detailed results obtained from research, application conditions, and advantages with other methods.

Digital watermarking technology had originally been studied as a copyright protection technology for digital content. Copyright protection of digital content has become increasingly important as it has been progressively more distributed throughout various media because it consists of digital data that can easily be copied, which are exactly like that in the original. Digital watermarking is an effective way of protecting copyrights from being illegally copied and various techniques of digital watermarking for digital content have been developed [2]–[9].

Out of all the techniques to process various kinds of content, those for images have been studied and developed the most. Digital watermarking of image content is embedded in digital images in various ways. Embedded watermarking is invisible when the images are displayed in most of these ways. Although it is invisible, it can be read out by applying digital processing to image data.

Digital watermarking has also been used in printed images, where digital watermarking is embedded in the digital data before the images are printed [10]–[13]. This is to prevent the images from being copied from printed images by digital cameras or scanners. The watermarking in this case is read out from the image data produced by digital cameras or scanners.

However, whether digital watermarking is in the digital data of an image, in a displayed image on an electronic display or in a printed image, conventional digital watermarking rests on the premise that people who want to protect the copyrights of their digital content, i.e., content creators or content providers, have the original digital data and they can embed watermarking in the original digital data by digital processing.

However, this premise does not apply to some cases. Let us assume that a person took a picture of a painting at a museum with a digital camera. Since recent digital cameras are highly advanced, captured images have very high levels of quality and if the painting is invaluable as a portrait, e.g., an artwork that has been painted by a famous artist, the captured image of such an irreplaceable painting may be extremely expensive. Therefore, the portrait rights of well-known paintings should be protected. However, images captured with digital cameras do not have watermarking in this case because they have been captured by visitors to museums who are not interested in protecting portrait rights; therefore, they are susceptible to illegal use.

The portrait rights or copyrights of such images should be protected. We previously proposed a technology that could prevent the images of objects from being used in such cases [14], [15]. It used illumination that contained invisible watermarking. As the illumination contained the watermarking, the images of photographs of objects that were illuminated by such illumination also contained watermarking. We demonstrated the feasibility of this technique and demonstrated that this technique could also be applied to objects with curved surfaces [16]. We produced watermarking by spatially modulating the brightness of the illumination.

Accuracy in reading embedded information from the captured image of a real object is one of the most important evaluation indexes. Sufficient accuracy has not been obtained for various kinds of images when the amplitude of modulation has been small by using watermarking produced by modulating the brightness of illumination because the invisibility of watermarking in the degree of modulation

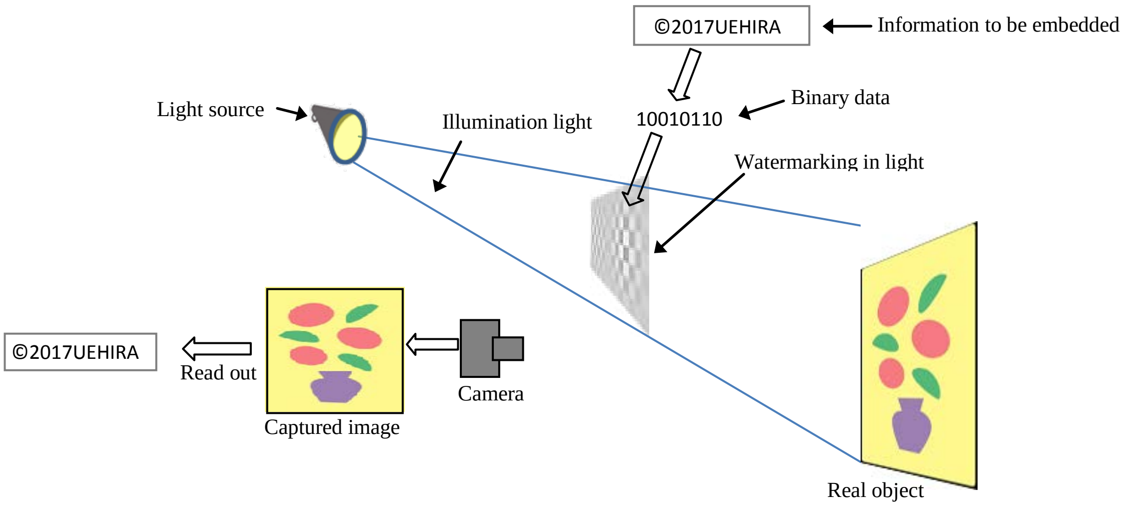


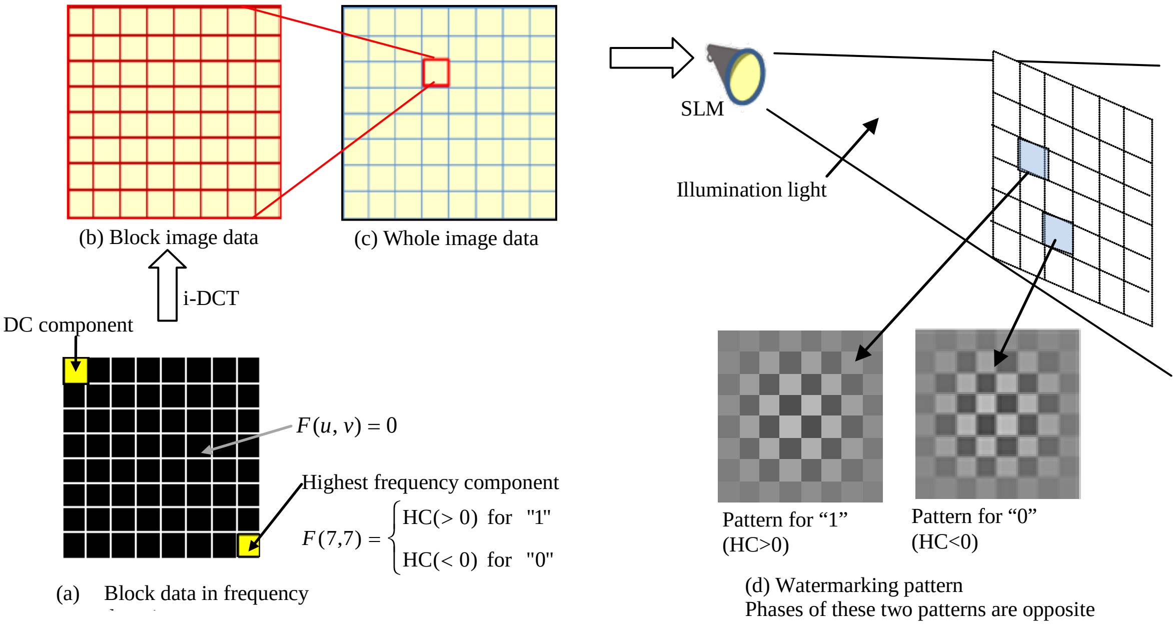
Figure 1. Basic concept underlying proposed technology

needs to be as small as possible. We studied a technique of watermarking using color difference-modulated light in this study to improve accuracy in reading embedded information. Uchida et al. used color difference signals to produce watermarking in digital images [17]. This was different from their method that produced watermarking with lighting that illuminated real objects; on the other hand, they electronically generated it directly in the digital images.

This paper is structured as follows. Section II explains the optical watermarking we propose and have studied thus far. Section III presents a new technique we used in this study that used color difference. Section Ⅳ describes simulations we conducted to evaluate the readability of the watermarking from captured images with the new technique. Section Ⅴ presents the results obtained from an experiment and discusses them. Section Ⅵconcludes the paper.

II. EMBEDDING WATERMARKING IN ILLUMINATION AND RELATED WORK

Figure 1 outlines the basic concept underlying our watermarking technique using illumination light to embed a watermark. An object is illuminated by projected light that



(b) Block image data

(c) Whole image data

(a) Block data in frequency

Pattern for “1” (HC>0)

Pattern for “0” (HC<0)

(d) Watermarking pattern
Phases of these two patterns are opposite

Figure 2. Procedure for producing optical watermarking

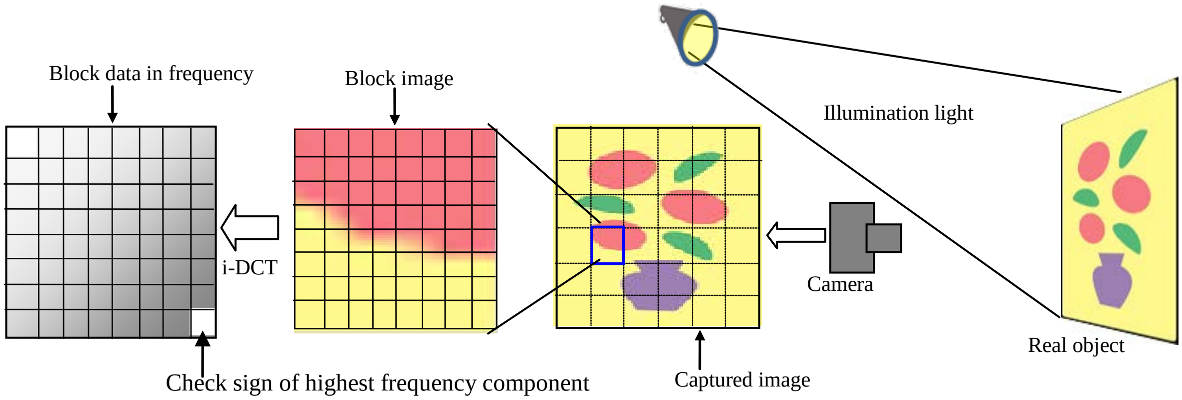


Figure 3. Procedure for reading out embedded information from captured image

contains an invisible watermark. A photograph taken of the object illuminated in this way would also contain the watermark. The watermark can be extracted in the same way as that used in conventional watermarking techniques for digital content.

There are various ways of possibly producing optical watermarking. Figure 2 illustrates the procedure for producing optical watermarking in our previous studies. A watermarking pattern was produced by modulating the brightness of the illumination light. First, we produced a watermark pattern as image data. The whole image area that corresponds to the illumination area in Fig. 2 is divided into numerous blocks. Each block has 8 x 8 pixels. First, each block datum is expressed in the frequency domain. Each block only has a DC component and a highest frequency component (HC) in both the x and y directions. The DC components in all blocks have the same value and they provide the brightness of illumination. The absolute value of HCs is the magnitude of modulation in brightness. We express one-bit binary data to be embedded by the sign of the HCs, i.e., if an HC is positive, it is expressed as "1" and if it is negative, it is expressed as "0". After the HCs for all blocks have been set, data in the frequency domain are converted to those in the space domain as image data by inverse discreet cosine transformation (i-DCT), and they are then input to a space light modulator (SLM) and changed to illumination light that illuminates real objects, such as paintings. We could use a commercial projector as an SLM for this purpose. Fig. 2 (d) shows the watermarking pattern in the light. These two patterns are for the "1" and "0" of binary data and the phases of these two are opposite.

The image of the object captured with a camera, $I(x,y)$, is given as a product of the reflectance of the object surface, $R(x,y)$, and the luminance of the projected light, $L(x,y)$, as:

$$I(x,y) = kR(x,y)\{L(x,y) + L_0\}, \tag{1}$$

where L_0 is bias luminance, such as that produced by room light and k is a constant.

The captured image also has a high-frequency pattern produced by modulating brightness because, as derived in Eq. (1), it is given by the product of the reflectance of the object surface and the luminance of the illumination light that contains the high-frequency pattern. This means the captured image also contain watermarking.

The watermarking pattern in the light and in the captured image cannot be seen by the human visual system because it is modulated at the highest frequency and the amplitude of modulation is small.

Figure 3 illustrates the procedure for reading out embedded information from a captured image. A captured image is divided into blocks in similar ways as that in the original, and then the pixel data in each block are converted into data in the frequency domain by discreet cosine transformation (DCT). Finally, the embedded data are read out by checking the sign of the HC for each block.

A technique based on a similar concept has been proposed by Zhou et al. [18] in related work. They temporally modulated the brightness of light by using a digital light processing (DLP) display. Although this was the same in terms of invisibly embedding information in projected light, luminance was temporally modulated it could not be applied to our purposes because our technology was targeted at shooting still images. Moreover, a method of using near infrared light has been studied [19] from the viewpoint of invisibly embedding information in light. Although this technique exploited the differences between sensory perceptions of humans and devices, it had the disadvantage that embedded information was eliminated by using an infrared cut filter.

III. OPTICAL WATERMARKING USING COLOR–DIFFERENCE MODULATION

We evaluated a method of producing watermarking in this study by modulating color differences instead of brightness. Luminance, i.e., chroma-blue and chroma-red (YCbCr) signals, was used to produce the watermarking. The basic procedure for producing the watermarking was the same as that in our previous study where we produced watermarking by modulating the brightness, Y. First, we produced the

(a) Image A (b) Image B

(c) Image C (d) Image D

Figure 4. Images used as objects in simulation.

original data of the color difference, Cb, as the frequency domain data for each block, then converted them into a block image in the space domain by i-DCT, and combined all block images into one image. The Y and Cr components were constant. After the YCbCr were converted into a red, green, and blue (RGB) signal, the RGB signal was input to a projector, and the watermarking pattern was projected onto the object.

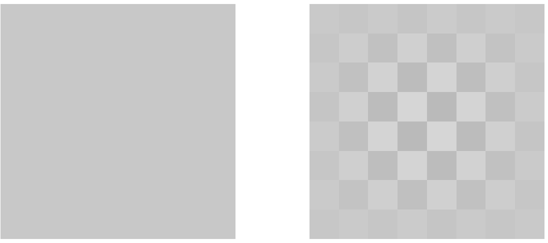
A captured image was first converted into a YCbCr signal, and then the Cb component was divided into blocks and converted into data in the frequency domain by using DCT. Finally, the embedded data were read out by checking the sign of the HC of the Cb for each block in the same way as the method outlined in Fig. 3.

IV. SIMULATION

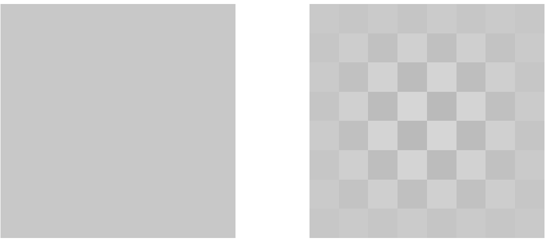
We evaluated the technique that used color difference modulation, which was explained in Section Ⅲ, by simulating the procedure in Fig. 3. The image data, *I(x,y)*, of an object that was captured with a camera were obtained using Eq. (1).

We used standard images as objects that had 512x512 pixels, as shown in Fig. 4, i.e., we used RGB pixel values of standards images as the reflectance of the object surface, *R(x,y)*, in Eq. (1).

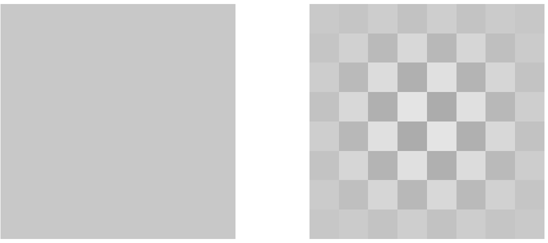
We first generated the initial data of Cb in the frequency domain for *L(x,y)* in Eq.(1), as shown in Fig. 2 (a). The data were generated for each block that had 8 x 8 components. Therefore, the *L(x,y)* used in this simulation is given as:



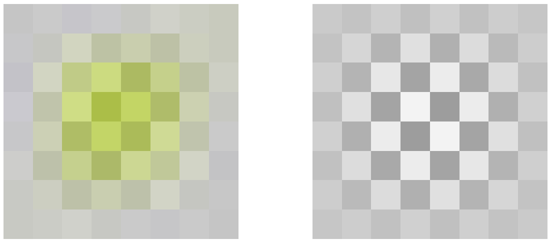
(1) HC=5 (1) HC=5



(2) HC=10 (2) HC=10



(3) HC=15 (3) HC=15



(4) HC=20 (4) HC=20

(a) Modulating Cb (b) Modulating Y

Figure 5. Luminance distribution images of projected light L(x,y) These are magnified images of block

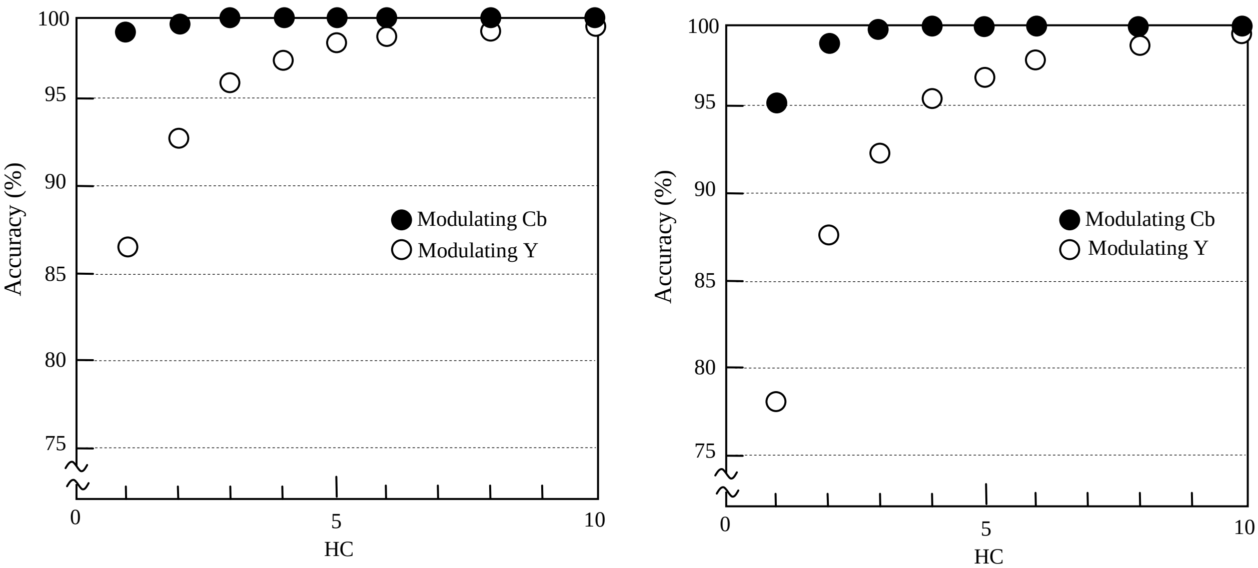
$$L(x,y)=\frac{1}{4}\sum_{u=0}^{7}\sum_{v=0}^{7}C(u)C(v)F(u,v) \times\cos\frac{(2m+1)u\pi}{16}\cos\frac{(2n+1)v\pi}{16}, \qquad (2)$$

where m and n are the pixel coordinates within the block and are given as:

$$m=\operatorname{mod}(512,y) \text{ and} \qquad (3)$$

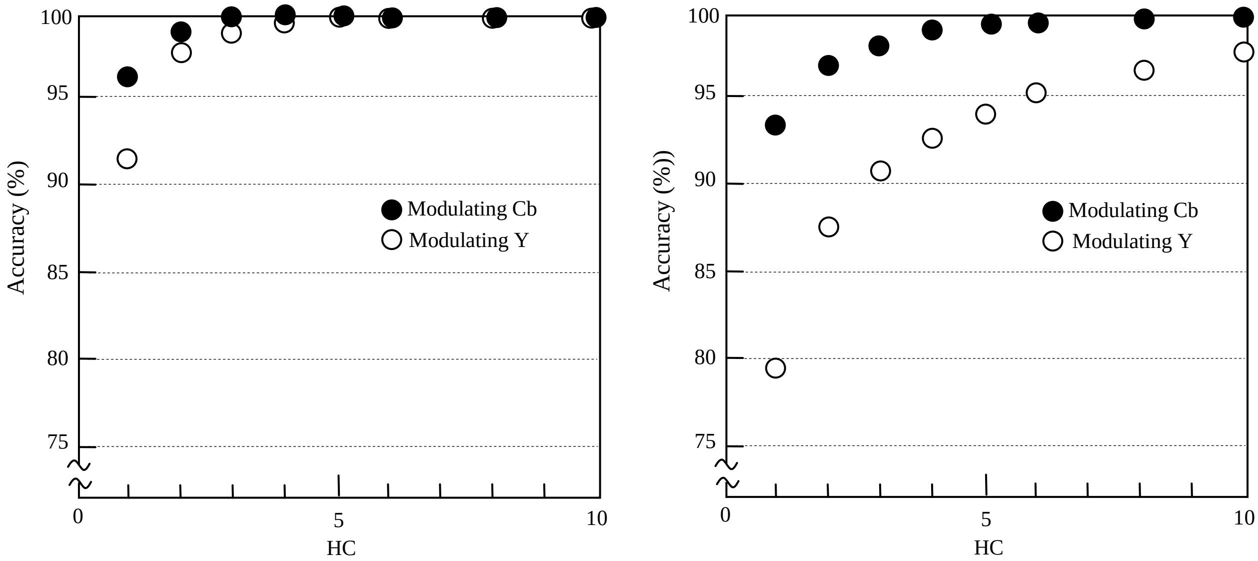
$$n=\operatorname{mod}(512,x)\,. \qquad (4)$$

Here, mod (*i*,*j*) represents the remainder when *i* is divided by



(a) Image A

(b) Image B



(c) Image C

(d) Image D

Figure 6. Accuracy in reading out binary data.
Accuracy indicates percentage of data correctly read out from 4096 binary data.

j. $F(u,v)$ in Eq. (2) is given as:

$$F(u,v) = \begin{cases} 200 & \text{for} \quad u,v = 0 \\ HC & \text{for} \quad u,v = 7 \\ 0 & \text{for} \quad u,v \neq 0 \text{ or } 7 \end{cases} \qquad (5)$$

The number of blocks of the initial data in the frequency domain was set to 64 x 64 (=4096) to make the number of pixels of $L(x,y)$ equal the number of pixels of $R(x,y)$, i.e., 512 x 512. The signs of the highest frequency component (HC) for each block were determined depending on whether to embed “1” or “0” in that block. The same number of “1” and “0” were randomly embedded. The magnitude of HC in the original data was changed from one to 20 as an experimental parameter, while Y, Cr, and L_0 were set to correspond to constant values of 200, 0, and 40. These values were the gray levels of image data whose maximum was 255. We embedded a watermarking pattern for reference by using our previous method, where we modulated Y. Here, Cb and Cr were set to zero, and L_0 was set to 40. Figure 5 has images of $L(y,x)$ when HC was 5, 10, 15 and 20. These images are magnified images of a block.

After $I(x,y)$ was derived with Eq. (1) and it was converted into YCbCr format data, it was divided into 4096 (64 x 64)

TABLE I ACCURACY IN READING OUT BINARY DATA

Magnitude of HC	**Accuracy in reading out binary data (%)**							
	Image **A**		Image **B**		**Image C**		**Image D**	
	Modulating Cb	**Modulating Y**	**Cb**	**Y**	**Cb**	**Y**	**Cb**	**Y**
HC=1	99.1	86.8	95.2	78.4	95.9	91.6	79.6	93.6
2	99.9	92.5	99.1	87.8	99.6	97.9	87.5	97.0
3	**100.0**	95.6	99.7	92.5	99.9	99.3	90.7	98.2
4	**100.0**	97.5	99.9	95.6	99.9	99.6	92.7	99.0
5	**100.0**	98.4	99.9	97.0	99.9	99.7	94.3	99.3
6	**100.0**	98.7	99.9	97.9	**100.0**	99.9	95.2	99.4
8	**100.0**	99.3	**100.0**	99.1	**100.0**	99.9	96.8	99.8
10	**100.0**	99.4	**100.0**	99.7	**100.0**	**100.0**	97.8	99.9
12	**100.0**	99.5	**100.0**	99.9	**100.0**	**100.0**	98.6	99.9
14	**100.0**	99.6	**100.0**	99.9	**100.0**	**100.0**	98.9	**100.0**
16	**100.0**	99.6	**100.0**	99.9	**100.0**	**100.0**	99.1	**100.0**
18	**100.0**	99.7	**100.0**	99.9	**100.0**	**100.0**	99.2	**100.0**
20	**100.0**	99.8	**100.0**	99.9	**100.0**	**100.0**	99.3	**100.0**

blocks, each whose 8 x 8 pixels and Cb components were converted into data in the frequency domain by the DCT for each block.

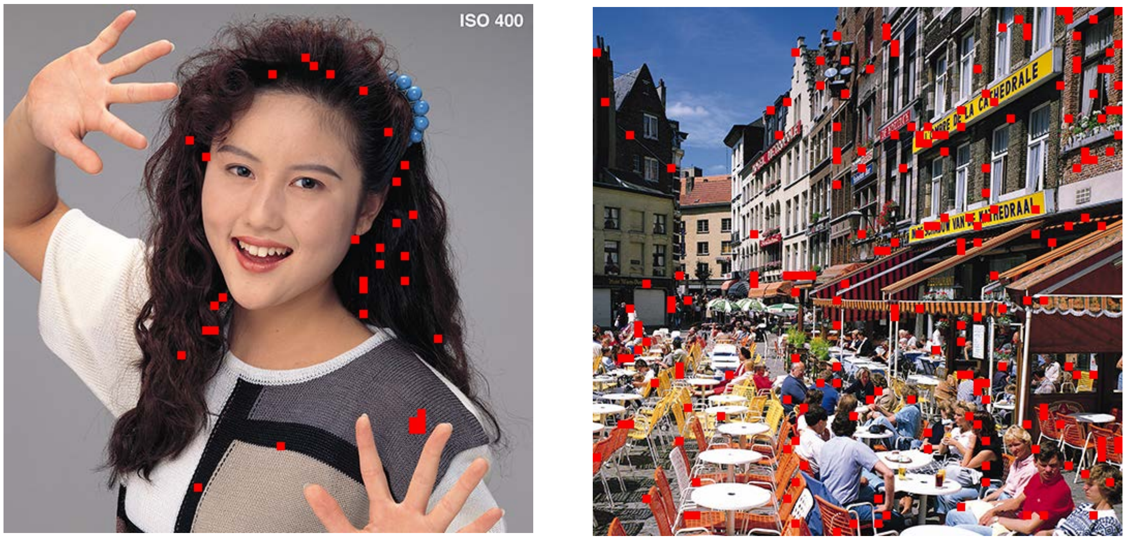
Embedded data were read out by checking the sign of the highest frequency component of the Cb for each block. The accuracy with which data were read out was evaluated based on the percentage of data that were correctly read out from 4096 binary data.

V. RESULTS AND DISCUSSION

Figure 6 and Table I indicate the accuracy with which the binary data were read out. The results reveal that the accuracy when Cb was modulated is higher than that when Y was modulated for all four images. When Cb was modulated, the accuracy for Image A was over 99 % even at the HC of one, and it reached 100% when HC was three. It was over 99% for HC over two for Images B and C. That for Image D was over 99% for HC over four. The accuracies for all these four images reached 100% at HCs of 6–14. In contrast, the accuracy when Y was modulated was smaller by over 10% than that when Cb was modulated for the HC of one. They became 100% for HCs over 10.

It can be seen from Fig. 6 and Table I that the accuracy differs depending on images. Figure 7 indicates where the readout errors occurred in each image when color differences were modulated and presents the results when HC was set to one. The areas in red in the images are blocks in which errors had occurred. It can be seen from Fig. 7 that errors particularly tended to occur in dark, yellow, and other areas that contained fine textures. This is because the reflectance there was low and the high frequency component became so small that the sign was reversed under the influence of a slight amount of noise. It is also reasonable for errors to have tended to occur in finely textured areas because such areas contained large high frequency components and functioned as noise for watermarking. The main reason the errors occurred in yellow areas is that the Cb component of YCbCr was very small for these areas because yellow does not contain blue components.

Figure 8 is a reference that shows blocks where readout errors occurred in images when watermarking was generated by modulating brightness Y. It can be seen that there are many errors that occurred on the pattern edge. Not many such errors can be seen when Cb was modulated, as indicated in Fig. 7. Blocks marked A to D, which are



(a) Image A

(b) Image B

(c) Image C

(d) Image D

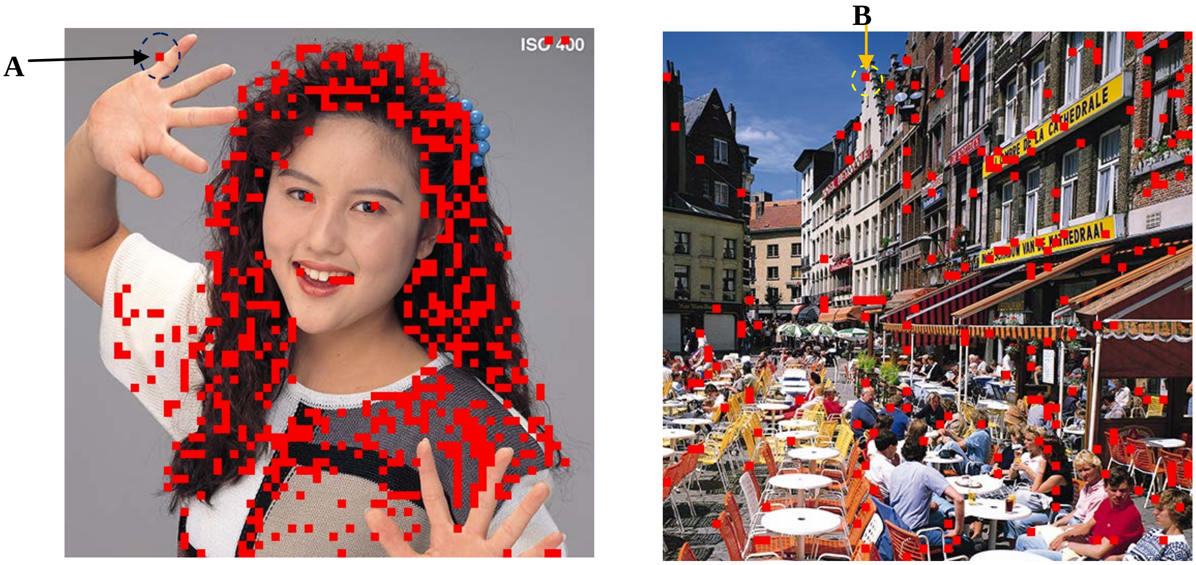
Figure 7. Blocks where readout error occurred when HC was set to one. Red squares indicate blocks where readout error occurred.

surrounded by dashed circles in Fig. 8, are examples on pattern edges where errors occurred. The magnitude of the highest frequency component, F(7,7), in these blocks in the original image that was not modulated are summarized in Table II , where it can be seen that the highest frequency component for Y is larger than that for Cb. Therefore, when watermarking was generated by modulating Y, the influence of the high frequency component of the object image was more strongly received in the positive/negative determination of the highest frequency component of the modulated image. This is the main reason the accuracy when Cb was modulated was higher than that when Y was modulated.

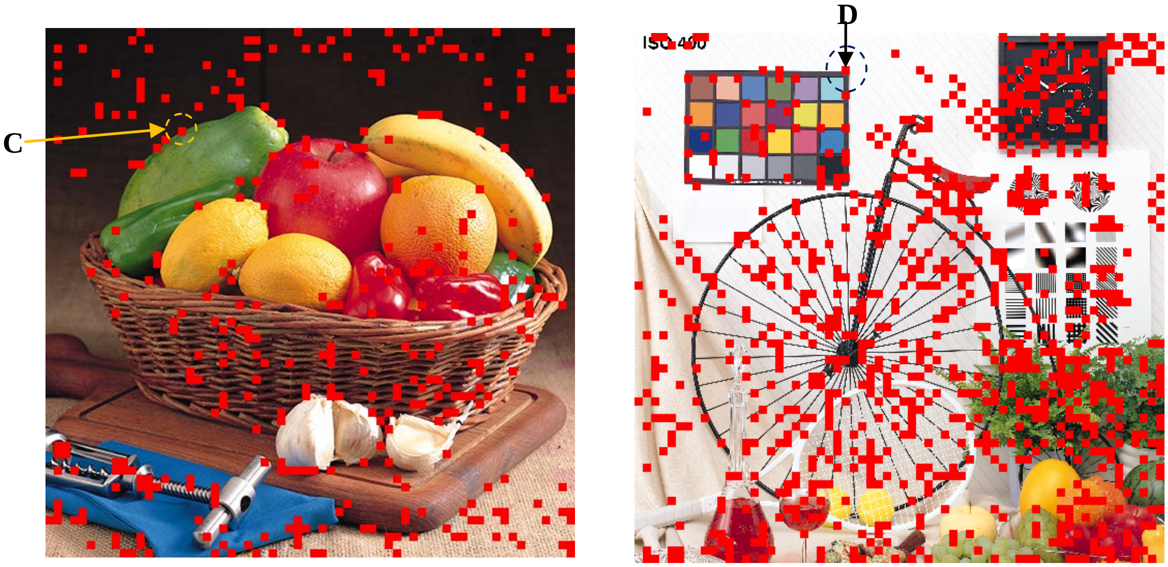
It is possible that these two methods can improve the accuracy with which the embedded data are read out by taking into consideration the results in Fig. 6, Fig. 7, and Table I . The first method involves embedding watermarking by avoiding error-prone areas, such as dark and yellow areas.

TABLE II EXAMPLES OF VALUE OF HIGHEST FREQUENCY COMPONENT OF BLOCK ON PATTERN EDGE

	Y	Cb
A	-1.29	0.41
B	0.75	0.64
C	-0.29	0.08
D	0.80	0.08



(a) Image A (b) Image B



(c) Image C (d) Image D

Figure 8. Blocks where readout errors occurred when luminance was modulated (HC= 1). Red squares indicate blocks where readout errors occurred.

The second entails the use of error correction techniques, where many of these are used in the fields of communication. We used majority voting as an error correction method in our previous study [14], where we also used brightness modulation. It embedded the same 1-bit data into three blocks that were sufficiently separated from one another and when embedded data were read out, we decided whether to use majority voting if their readout data differed. Accuracy reached 100% even it was less than 90%. This technique of modulating color differences can be very accurate by combining it with error correction technologies.

Figure 5 indicates that modulating Cb is superior to modulating Y in terms of invisibility. Consequently, the technique of modulating Cb is better than that of modulating Y for both the readability and invisiblity requirements of embedded watermarking. Figure 9 presents the captured images simulated by using Eq. (1) when HC was set to five. We could not see any watermarking patterns in the images. These results indicate that we could satisfy both the invisibility and readability requirements of embedded data by using appropriate HC ranges.

(a) Image A (b) Image B

(c) Image C (d) Image D

Figure 9.Captured images simulated using Eq. 1 when HC was set to five

VI. CONCLUSION AND FUTURE WORK

We developed a technique that could embed an invisible watermarking pattern into captured images of real objects using illumination that contained the pattern. We embedded the pattern into the illumination by modulating color differences.

We discovered four main findings through simulation in this study. The first was that the accuracy when modulating Cb was higher than that when modulating Y. The second was that errors in reading out embedded binary data particularly tended to occur in dark, yellow, and other areas that contained fine textures. The third was that we could satisfy both the invisibility and readability requirements of embedded data by using appropriate HC ranges. The fourth was that we found that this technique of modulating color differences could be a very accurate method when combined with error correction technology.

We intend to examine detailed conditions on the invisibility of watermarks in the future. Future research will also involve quantitatively finding what effects there are when error correction is added to the technique proposed in this research. Moreover, we will examine the effects of image compression on the accuracy with which embedded information could be read out because the captured image has been handled in compressed form in many cases.

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REFERENCES

[1] K. Uehira and H. Unno, “Optical Watermark Pattern Technique using Color–Difference Modulation,” Proceedings of PATTERNS 2017, 2017.

[2] I. J. Cox, J. Kilian, F. T. Leighton, and T. Shamoon, "Secure spread spectrum watermarking for multimedia,” IEEE Trans. Image Process., Vol. 6, No. 12, pp. 1673–1687, 1997.

[3] M. D. Swanson, M. Kobayashi, and A. H. Tewfik, “Multimedia data-embedding and watermarking technologies,” Proc. IEEE, Vol. 86, No. 6, pp. 1064–1087, 1998.

[4] M. Hartung and M. Kutter, “Multimedia watermarking techniques,” Proc IEEE, Vol. 87, No.7, pp. 1079–1107, 1999.

[5] G. C. Langelaar, I. Setyawan, and R. L. Lagendij, “Watermarking digital image and video data,” IEEE Signal Processing Magazine, Vol. 17, No.5, pp. 20–46, 2000.

[6] J. Haitsma and T. Kalker, “A Watermarking Scheme for Digital Cinema,” ICIP2001, Vol. 2, pp. 487–489, 2001.

[7] Digital cinema system specification V1.2, Digital Cinema Initiatives, Mar. 2008.

[8] S. Goshi, H. Nakamura, H. Ito, R. Fujii, M. Suzuki, S. Takai, and Y. Tani, “A New Watermark Surviving after Re-shooting the Images Displayed on a Screen,” KES2005, LNAI3682, pp. 1099–1107, 2005.

[9] K. Okihara, Y. Inazumi, and H. Kinoshita, “A Watermark Method that Improves the Relationship Between the Number of Embedded Bits and Image Degradation,” IEIJ, Vol. 58, No. 10, pp. 1465–1467, 2004.

[10] T. Mizumoto and K. Matsui, “Robustness investigation of DCT digital watermark for printing and scanning,” Trans. IEICE (A), Vol. J85-A, No. 4, pp. 451–459, 2002.

[11] M. Ejima and A. Miyazaki, “Digital watermark technique for hard copy image,” Trans. IEICE (A), Vol. J82-A, No. 7, pp. 1156–1159, 1999.

[12] Y. Horiuchi and M. Muneyasu, “Information Embedding to the Printing Images Based on DCT,” Proc. of ITC-CSCC2004, No. 7F3P50-1-4, 2004.

[13] Z. Liu, “New trends and challenges in digital watermarking technology: Application for printed materials” in Multimedia Watermarking Techniques and Applications, B. Furht and D. Kirovski, pp. 289–305, Auerbach Publications, 2006

[14] K. Uehira and M. Suzuki, “Digital watermarking technique using brightness-modulated light,” Proceedings of the IEEE ICME2008, pp. 257–260, 2008.

[15] Y. Ishikawa, K. Uehira, and K. Yanaka, “Practical Evaluation of Illumination Watermarking Technique Using Orthogonal Tranforms,” Journal of Display Technology, Vol. 6, No. 9, pp. 351–358, 2010.

[16] M. Komori and K. Uehira, “Optical watermarking technology for protecting portrait rights of three-dimensional shaped real objects using one-dimensional high-frequency patterns,” Journal of Electronic Imaging, Vol. 22, No. 3, pp. 033004-1 to 033004-7, 2013.

[17] Y. Goto and O. Uchida, “Recognizable digital watermarking for printed materials embedding in hue component,” Proceedings of the IIEEJ Image Electronics and Visual Computing Workshop 2010, 2P-9, 2010.

[18] L. Zhou, S. Fukushima, and T. Naemura, “Dynamically Reconfigurable Framework for Pixel-level Visible Light Communication Projector,” Proc. of SPIE Vol. 8979 89790J-1, 2014.

[19] T. Yamada, S. Gohshi, and I. Echizen, “Re-shooting prevention based on difference between sensory perceptions of humans and devices,” Proc. of the 17th International Conference on Image Processing, pp. 993–996, 2010.