

Optically written watermarking technology using temporally and spatially luminance-modulated light

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Abstract

This paper describes a technique that can invisibly embed information into images captured with a video camera. It uses illumination that contains invisible patterns. As the illumination contains patterns, a captured image of a real object illuminated by such light also contains the same patterns. It uses a luminance modulated pattern whose amplitude is too small to be perceived. Four frames are used for a cycle of the modulating. The difference frame images of every other frame of the captured image over a certain period are added up. Changes in brightness by modulating are accumulated over the frames while the object image is removed because difference frame images are used. This makes it possible to read out the embedded patterns. The experimental results demonstrate that the embedded pattern is invisible and can be read out by choosing some conditions properly, although a small amount of noise results from the remaining object image.

Introduction

Information hiding in digital media has been studied for almost two decades [1], [2], and various applications for it have been developed. A typical example of information hiding technology is digital watermarking. It hides information in digital content such as that in images and music. The main purpose of this kind of technology has been to protect the copyrights of digital content. Digital watermarking is an effective way of protecting copyrighted content from being illegally copied.

Although conventional information hiding technologies hide information in digital data, we have studied a technique that does not hide information in digital data but conceals it in real objects [3–5]. The main purpose of this technique is to protect the portrait rights of real objects that are highly valued as portraits such as celebrated paintings in museums. Portrait right infringement happens when such a real object is photographed illegally and its image is published or distributed on the Internet. This technique uses light that illuminates the real object. It invisibly contains certain information. Since the illumination contains the information, the captured image of the object illuminated by such light also contains the same information. Although the hidden information is also invisible in the captured image, it can similarly be abstracted by digital processing for digital watermarking. Although the main purpose of this technique is to protect the portrait rights of real objects, various other applications are possible.

Although we have been studying this technique for still images, the need for this kind of technique for moving images has recently been growing because taking videos at any time and from anywhere has become easier than ever for everyone because of the widespread use of smart phones that have video cameras built into them. Here, we present a new technique that uses temporally brightness-modulated light to apply to videos. The amplitude of brightness modulation has to be very small to enhance the invisibility of hidden information. This makes it difficult to read

out hidden information. Therefore, we summed up tens of frames to magnify the signal of hidden information to enhance readability. We have studied this technique by simulation where still images modulated positively and negatively were summed up and confirmed the fundamental principle of the proposed technique [6]. When using moving images, the discrepancy between phases of the projected image and captured image becomes a problem because it reduces the signal of the readout pattern, and the embedded pattern cannot be read out in the worst case. This paper presents a technique that presupposes the discrepancy between phases of the projected image and captured image. It also describes the experiments we conducted to evaluate the technique using moving images and uses the experimental results to discuss the feasibility of the proposed technique.

Embedding and reading out the

Figure 1 illustrates the basic configuration for the technique we have been studying. The object is illuminated by light that contains an invisible pattern. This means that a very low contrast pattern that cannot be perceived by human vision is projected onto the real object. Since the pattern in the light is invisible, the object looks as if it were being illuminated by usual illumination. The image of the object illuminated by the light is captured by a video camera. Since the brightness of the captured image is given by the product of the reflectance of the object surface and the intensity of illumination on the surface, the captured image of the object illuminated by the light that contains a certain pattern also contains the same pattern even though it is invisible. In this way, this technique hides the pattern on a real object and embeds it in the image of the object captured with a camera.

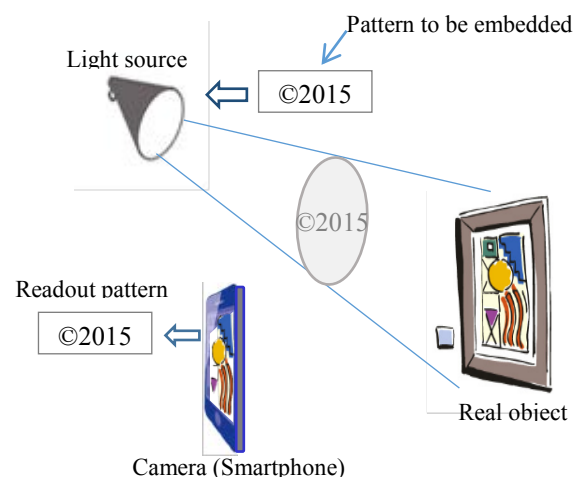


Fig.1 Basic configuration of technology.

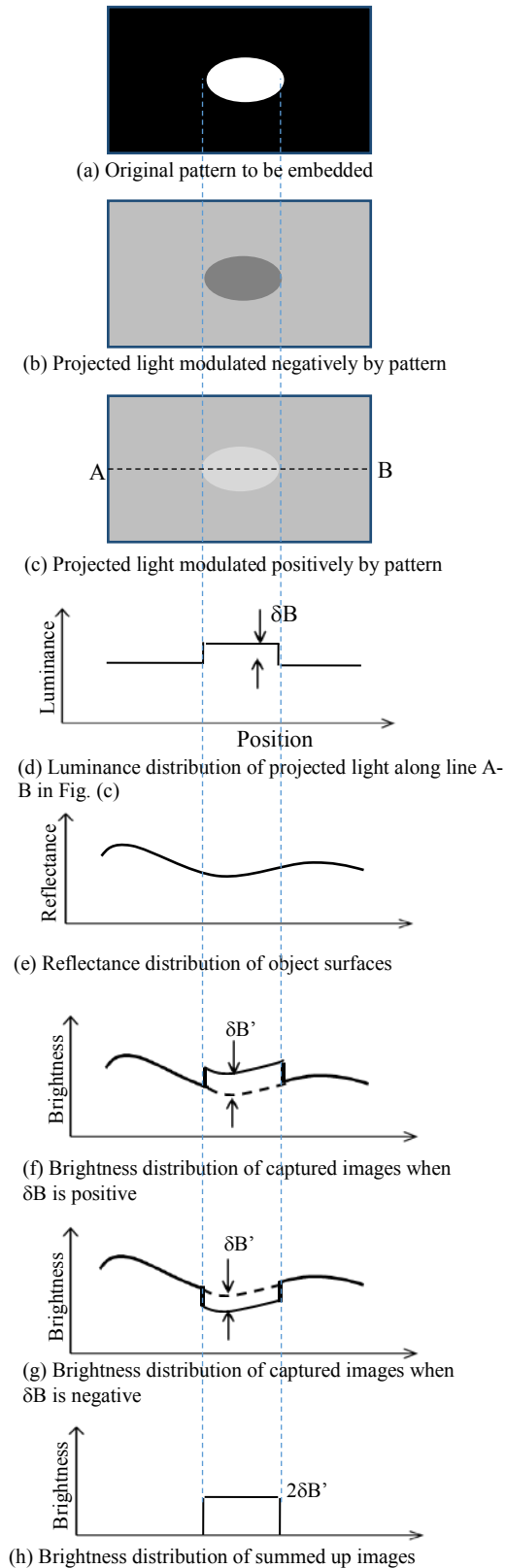


Fig.2 Basic principle of technology.

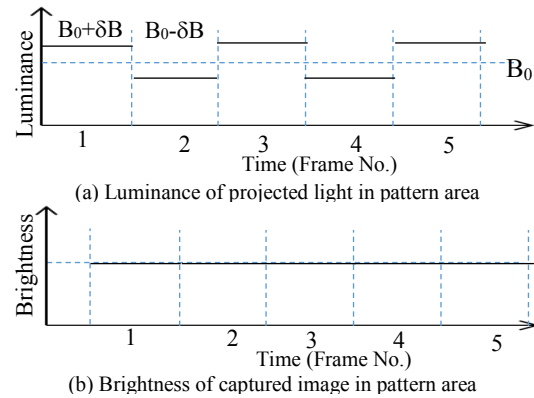


Fig.3 Example of phase discrepancy.

Figure 2 illustrates the basic principle for reading out the embedded pattern. Fig. 2 (a) shows the original pattern to be embedded. Fig. 2 (b) and (c) indicate the projected light modulated positively and negatively, respectively, by a pattern. Fig. 2 (d) indicates the luminance distribution of projected light along the line A-B in Fig. 3 (c). The luminance in the pattern area is made larger or smaller than that in the other area by δB , which is modulation amplitude. Fig. 2 (e) indicates the reflectance distribution of object surfaces. The brightness of the surface is proportional to the product of the reflectance of the surface and luminance of the projected light on the surface. This brightness is also relative to brightness of the captured image of the object. Fig. 2 (f) and (g) indicate the brightness distribution of captured images when δB is positive and negative. The brightness is the same in the area other than that where the pattern is embedded in both these images. Then, if the difference in the two images shown in Fig. 2 (f) and (g) is considered, the brightness in the difference image becomes zero in the area other than that where the pattern is embedded, and the brightness appears only in the area where the pattern is embedded. This brightness is small in the difference image of two frame images. However, if tens of difference images are summed up, the brightness of the embedded pattern is expected to be multiplied and the pattern seen clearly.

When moving images are used, the discrepancy between phases of the projected image and captured image reduces the signal of the readout pattern. Figure 3 indicates the example of phase discrepancy as the worst case. Fig. 3 (a) indicates the luminance of the projected light in the area where a pattern is embedded. It changes by $+\delta B$ and $-\delta B$ every frame with an averaged brightness B_0 . Fig. 3 (b) indicates the brightness of the captured image in the pattern area. The difference in phase of the projected light and captured image is 90 degrees (half-frame period). In this case, each frame of a captured image extends two consecutive frames of projected light equally as shown in Fig. 3, and as a result, the brightness of each frame becomes B_0 because $+\delta B$ and $-\delta B$ compensate for each other. Therefore, embedded pattern cannot be seen in the difference image between two consecutive frame images.

To solve the problem mentioned above, we used a four-frame modulation method. Figure 4 explains the basic principle of this method. It uses two frames for each positive and negative modulation. In this method, at least one of odd or even frame of the captured image does not extend over two types of frame of

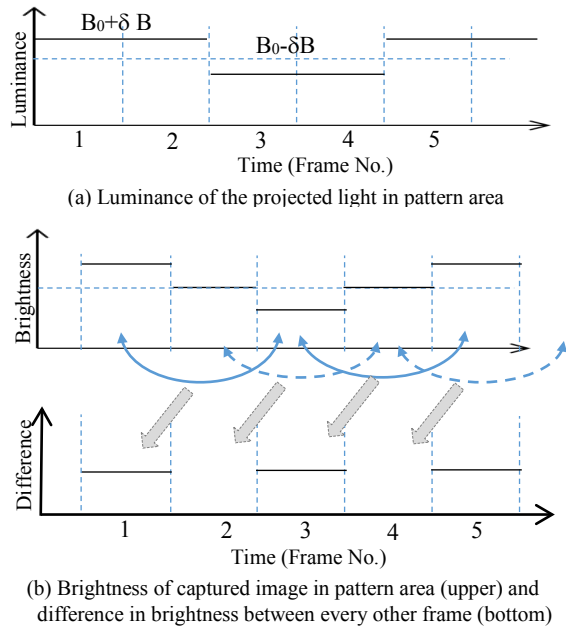


Fig.4 Four-frame modulation method

projected light where the luminance is positively and negatively modulated. Therefore, if we take the differences between every other frame of the captured image and sum them up over the frames, it is expected that the embedded pattern can be read out.

Experiment

We conducted experiments to evaluate the feasibility of the technique we propose. We used A1 printed images as objects. In addition to the printed images, we also used blank paper as a reference object.

We used an LCD projector that had 1280 x 1024 pixels to project a light with an embedded pattern onto printed images. The distance between the printed images and the projector was 2.10 m. The illumination on the blank paper was about 220 cd/cm² when we set the brightness of the projected image to 200.

We used a digital camera that had a CMOS image sensor with 4752x3168 pixels. We used its video function to save moving images with 1280 x 780 pixels using Motion-JPEG encoding.

Figure 5 has the patterns that we used for embedding, which were binary images. We produced the video images to be projected as illumination light that invisibly contained the patterns in Fig. 5. The brightness of the G-ch in the pattern embedded region was modulated. The brightness of all three channels was set to 200, and

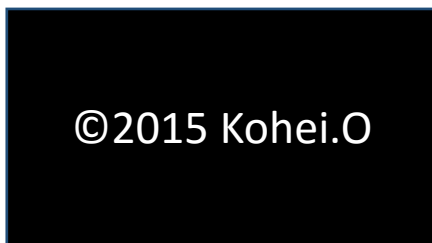
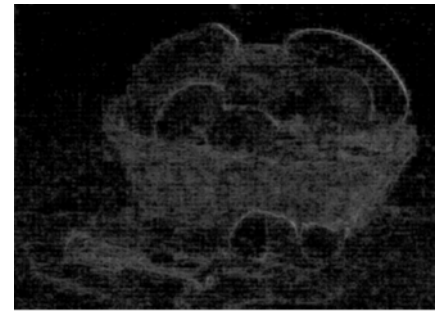
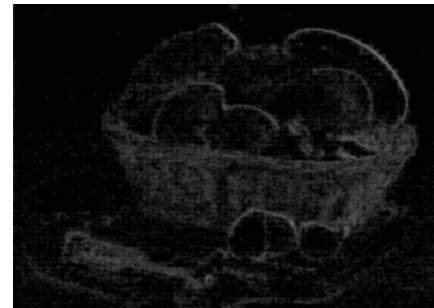


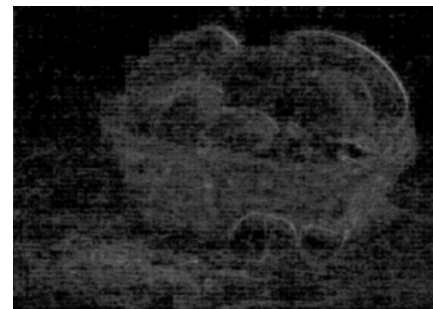
Fig.5 Patterns that we used for embedding



(a) R-ch.



(b) G-ch.



(c) B-ch.

Fig. 6 Frame summed-up image with no embedded pattern. Number of image is 30.

the amplitudes of modulation δB to embed the pattern in the green component were changed from four to 20 as experimental parameters. These figures indicate the gray scale values, the maximum of which was 255.

Results and discussion

Figure 6 shows the summed-up frame images when $\delta B=0$. The figure shows that the object image cannot be removed completely and still remains as noise. This noise decreases the S/N in reading out the embedded pattern. Noise is seen in every channel image, but that in the green channel is the lowest. These noises are considered to be caused by the processing for image compressing by Motion-JPEG, and the reason that noise in G-ch is the least among three channels is thought to be that changes in an image due to JPEG compression is least for G-ch among the three channels. Thus, we choose G-ch as that in which a pattern is embedded.

Figure 7 indicates the images of the objects (printed image and blank paper) on which a pattern of embedded light was projected.

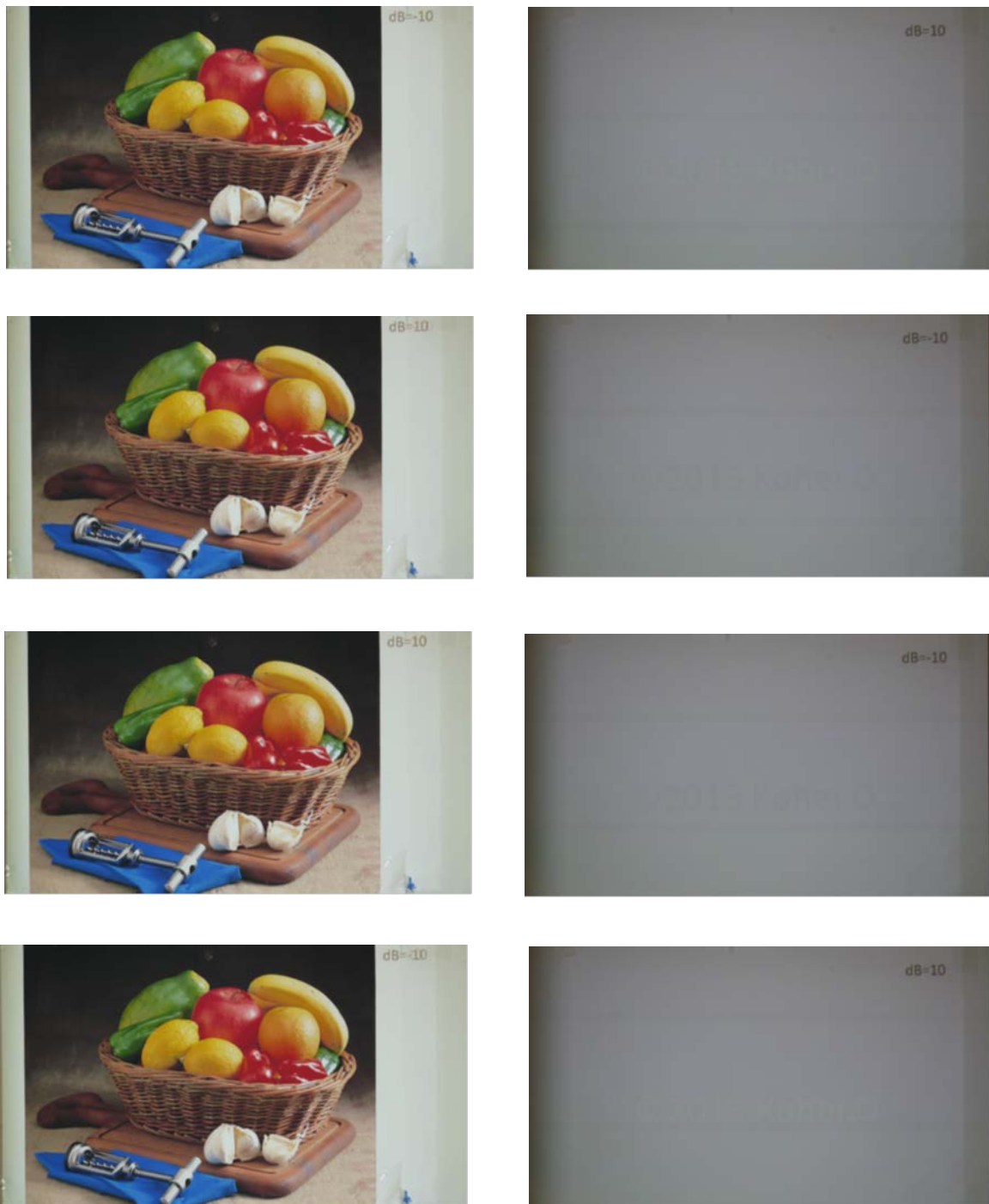


Fig. 7 Images of the objects (printed image and blank paper) ($\delta B=10$).

Modulation amplitude, δB , was 10. The four images from top to bottom are four consecutive frame images. It is seen that the embedded pattern cannot be seen when it is projected on the paper on which an image was printed, although it is seen slightly when projected on blank paper. From the result in Fig. 7, up to about 10

δB can be used for embedding the pattern from the viewpoint of invisibility.

Figure 8 indicates the frame-summed-up images. These images are cutouts of the object area. Images in the left column used blank paper as the object, and those in the middle and right columns used


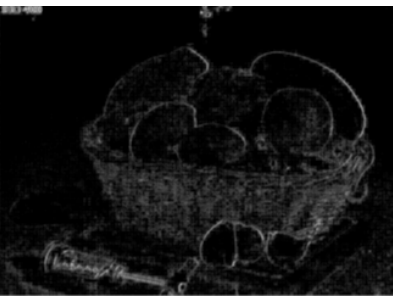

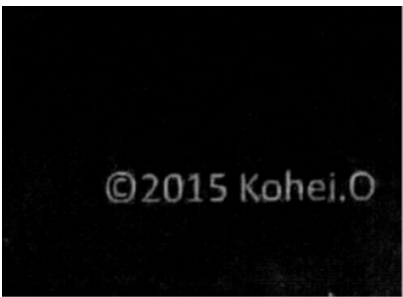

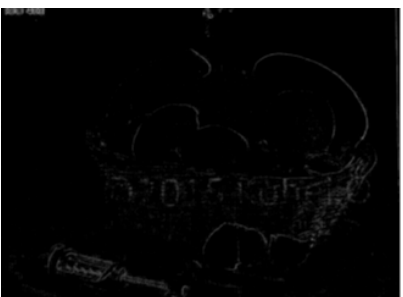
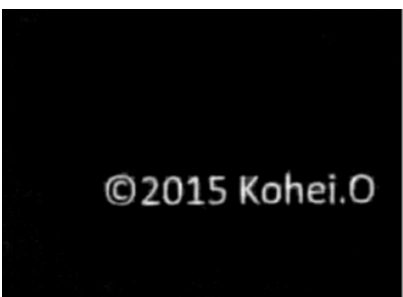


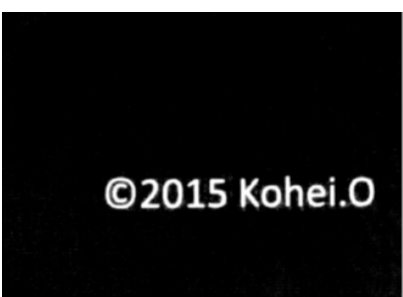


	Object: Blank paper Number of summed-up frames: 30	Object: Image printed paper Number of summed-up frames: 30	Object: Image printed paper Number of summed-up frames: 16
$\delta B=4$			
$\delta B=6$			
$\delta B=10$			
$\delta B=20$			

Fig. 8 Frame-summed-up images.

printed paper. The frame number used for summing up was 30 for those in the left and middle columns and 16 for those on right column. Fig. 8 shows that when blank paper is used as an object, the readout pattern is seen clearly for δB over 6. Fig. 8 also shows that when printed-image paper is used, the readout pattern becomes less clear because of the noise caused by the texture of the printed image, and the pattern can barely be seen for δB of 6 although it is

seen clearly for δB of 10 or more. These are images when the number of summed-up frames is 30. When the number of summed up frames is 16, the readout pattern becomes harder to see and it is seen barely for δB of 10 and clearly for δB of 20 or more.

From these results, the condition where δB is 10 and the number of summed up frame images is 30 is considered to be the optimum or near the optimum. However, if we could decrease the noise from

the object image, we would be able to use δB less than 10. This will be future work.

Conclusion

We studied a technique that can embed invisible information into images captured with a video camera. It uses illumination that invisibly contains patterns. As the illumination contains patterns, a captured image of a real object illuminated by such light also contains the same patterns. It uses a luminance modulated pattern whose amplitude is too small to be perceived. Four frames are used for a cycle of the modulating. To read out the embedded pattern, the difference frame images of every other frame of a captured image over a certain period are added up.

We conducted an experiment where we embedded patterns in the G-ch images. From the experiment results, we confirmed that this technique makes it possible to read out the embedded patterns while keeping the embedded pattern invisible. Moreover, experiment results showed that some noise remained in the frame-summed-up image that was considered to be caused by the processing for Motion-JPEG, and this noise reduced the clearness of the readout pattern. In future work, we will try to reduce this noise.

Moreover, in this study, we did not take in account the movement of the camera such as camera shake. The movement of the camera causes another noise, however, this kind of noise is expected to be removed by using a conventional camera shake correction technique. Confirming this is future work.

Acknowledgements

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Author Biography

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Hiroshi Unno received an M.S. degree in information science from the Japan Advanced Institute of Science and Technology, Hokuriku, Kanazawa, Japan, in 1996. He joined the Kanagawa Institute of Technology, Kanagawa, Japan, in 2001. Since then, he has been engaged in research on computer networks, formal methods, user interface, 3-D displays, and image processing.

Kazutake Uehira received his B.S. and M.S. in Electronics in 1979 and 1981 and his Ph.D. in 1994 all from the University of Osaka Prefecture, Japan. He joined NTT Electrical Communication Laboratories in Tokyo in 1981. Since then, he has been engaged in research and development on image acquisition technologies, display systems, and high-reality video communication systems. In 2001, he joined Kanagawa Institute of Technology, Japan, as a professor and is currently engaged in research on information hiding technology.