Robustness against Defocusing of Images in Optical Watermarking Technique

Yasunori Ishikawa
Member, IEEE
Kanagawa Institute of Technology
1030 Shimo-Ogino
Atsugi-shi, Kanagawa, Japan
yasu@yit-pe.com

Kazutake Uehira
Member, IEEE
Kanagawa Institute of Technology
1030 Shimo-Ogino
Atsugi-shi, Kanagawa, Japan
uehira@nw.kanagawa-it.ac.jp

Kazuhisa Yanaka
Member, IEEE
Kanagawa Institute of Technology
1030 Shimo-Ogino
Atsugi-shi, Kanagawa, Japan
yanaka@ic.kanagawa-it.ac.jp

***Abstract* -- We describes in this paper the robustness of optical watermarking against the defocusing of images, which usually occurs in images taken with digital cameras under non-optimal conditions. We evaluated measurements of the defocusing of images against the accuracy of detection of optical watermarking. The value of full width at half maximum (FWHM) of the Gaussian function was used to measure the defocusing of images. We found from the results of evaluation that optical watermarking technology was extremely robust against defocusing of images. As a result, we demonstrated the practicality of optical watermarking in a real-use environment along with the robustness against geometric distortion we previously proposed.**

***Index Terms*-- Digital watermarking, Optical watermarking, Spatially modulated illumination, Visible light communication.**

I. INTRODUCTION

Optical watermarking technology that we previously proposed has a unique feature that can be used to embed invisible digital watermarking information into the image data of real objects with spatially modulated illumination. Therefore, images of objects with no copyright protection such as pictures painted by famous artists in museums can be prevented from being illegally photographed with this technology. As conventional watermarking technology is based on the premise that digital data are possessed by their owners, it is difficult to protect objects that have not been produced with digital data. Optical watermarking technology can offer the solution to such a difficult situation.

We have conducted various practical proof experiments in consideration of a real-use environment. We used orthogonal transforms such as a Discrete Cosine Transform (DCT) or a Walsh-Hadamard Transform (WHT) as methods of embedding the watermarking [6][8]. We also previously proposed techniques that were robust against geometrical distortions due to the shooting and reflectance conditions of objects under practical conditions [10]. Moreover, we proposed optimizing the pixel sizes of blocks in watermarked images, which indicated the optimal conditions for pixel sizes of blocks between the accuracy of detection and the volume of content [11]. However, if the practical environment where illegal photographs are being shot is taken into account, the distance from which a photograph of an object is being taken may not be the optimal position when focusing is considered. We evaluated the possibility of detecting the optical watermarking in a defocused image that was produced under such photographic conditions, and demonstrated that optical watermarking has a strong tolerance against defocusing.

II. MEASUREMENT OF DEFOCUSING

Defocused image data that are produced for an object image can be expressed with convolution with a point-spread function (PSF). Here, we used full width at half maximum (FWHM) to measure defocusing, where a Gaussian function was used to approximate PSF. We measured the defocusing value in the experiments that followed using the response of the density value by scanning isolated point images one-dimensionally (horizontally). Therefore, a line-spread function (LSP) could be equivalently adapted to approximate a one-dimensional Gaussian function. A one-dimensional normalized Gaussian function whose surface area for the whole integration domain is 1 is expressed by:

$$h(x) = \sqrt{\frac{2.7725887}{\pi w^2}} \exp\{-\frac{2.7725887(x-x_0)^2}{w^2}\}, \qquad (5)$$

where w is FWHM, which indicates the horizontal width of the Gaussian function at half its maximum value. The convolution with normalized Gaussian function $h(x)$ given in Eq. (5) to object image $f(x)$ is expressed by:

$$g(x) = \int_{-\infty}^{\infty} f(x')h(x-x')dx' \cdot \qquad (6)$$

To maintain consistency with the data in the experiments, $f(x)$ was set to a rectangular function that was 11 pixels in width and 24 pixels in height, and convolution was calculated with the one-dimensional Gaussian function with w pixel(s) of FWHM. The simulated waveforms for the response of the density value of defocused images were produced from the calculation results. Fig. 1 has the simulated waveforms for the response of the density value, where FWHM was set from 1 to 15 pixels (all odd pixels).

III. EXPERIMENTS AND RESULTS

We first generated image data that were stuck on the right and left of the watermarked image produced using orthogonal transforms and an image on which only four 2×2-pixel isolated points were drawn. DCT and WHT were used as

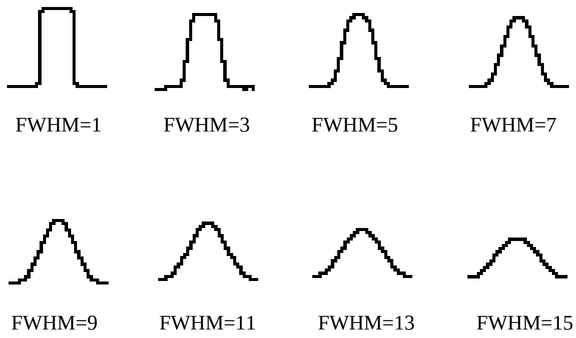

Fig. 1. Simulated waveforms for response of rectangular function (Unit of FWHM: Pixel)

Fig. 2. Obtained image used in experiment
- Left: Isolated points for measuring defocusing
- Right: Watermarked area

orthogonal transforms in the experiments. In both cases, the highest frequency component (HC) in the frequency space of image data was used to embed 1-bit watermarking information in all 8×8 pixels blocks. Also a DC component in frequency space was given as an average brightness for the entire area for watermarking, and the other components were set to "0". Therefore, the embedded information for watermarking was easily separated from the object image, because the frequency components of the object image itself were usually lower than HC.

We used two methods of embedding the data. The first, "1-block method", involved embedding 1-bit data into one block. The second, "majority method", involved embedding the same 1-bit data into three blocks sufficiently separated from one another, and the readout data were determined by majority decision. The latter method might have improved the accuracy with which the embedded data were read out.

The generated image data were projected with a projector, where the watermarked image area was projected onto printed standard image data that was A4 in size as an object and the area with isolated points was projected onto white paper that was on the same plane. The watermarked image that was generated as binary watermarking information was embedded as blocks of "0" and "1", which were alternately placed like those on a checkerboard pattern. We took a picture of the projected image with a digital camera. Fig. 2 shows an example of the image data we obtained. We used a Digital Light Processing (DLP) projector with a resolution of 800×600 pixels and a digital camera with a resolution of 4288×2848 pixels. The distance from the projector to the object image plane was about 1.1 m, and the distance from the lens surface of the digital camera to the object plane was about 1.3 m. A zoom lens was mounted on the digital camera and a 70-mm focal length was used. The irradiated watermarked image area on the printed object image was about 105×105 mm, and the pixel size of the area in the image we obtained with the digital camera was about 800×800 pixels. We acquired image data for the isolated points and the watermarked image by fluctuating the focal length slightly.

We carried out the following process on the image data we acquired. Pixels in the area with isolated points were scanned horizontally on an approximately centered line on the isolated points and density histograms of pixels of the images with the same focal length were generated. By comparing these density histograms with the simulated waveforms for the response of the density value, the FWHM of LSP was identified. Identification was undertaken by comparing the pixel width at a height of 23 pixels from the base of the wave. However, when the height from the base was under 23 pixels, the maximum height of the waveform was used for identification. A rectangle in the watermarked area was clipped out from the acquired image data as a watermarked area and a forward orthogonal transform corresponding to the method with which watermarking was produced was applied to the clipped out area. Then, embedded binary information was read out and the rate at which blocks were correctly read out was determined by checking the HC value of all blocks in the area, where blocks embedded with "1" and "0" were alternately placed like those on a checkerboard. The accuracy of detection was measured from these results.

Figs. 3 (a)-(d) has magnified images of the isolated points and the watermarked area, and the histograms for the density value, which are of the acquired images identified as FWHM=3, 7, 8, and 11. Figs. 4 (a)-(d) also has the accuracies of detection as the values of FWHM are experimental parameters. The distance between blocks in the majority method that had the same information was set to five in the experiments.

IV. Discussion

As can be seen in Fig. 4, when FWHM was seven pixels or less in defocusing images, an accuracy of detection of 100%

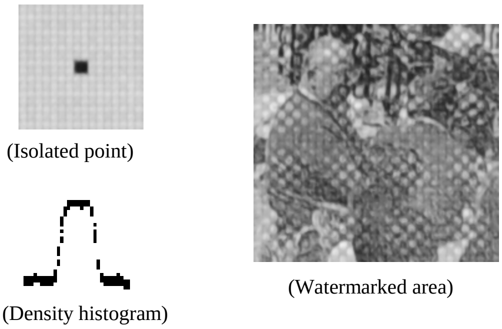

Fig. 3. (a) Part of magnified image and density histogram
(FWHM=3, DCT, DC=150, HC=15)

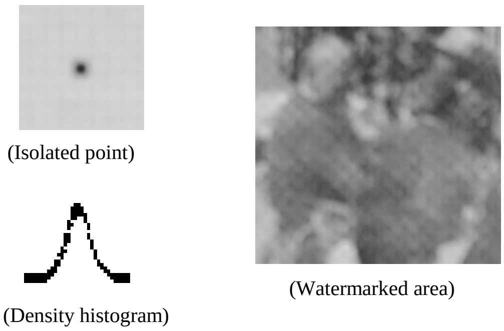

Fig. 3. (b) Part of magnified image and density histogram
(FWHM=7, DCT, DC=150, HC=15)

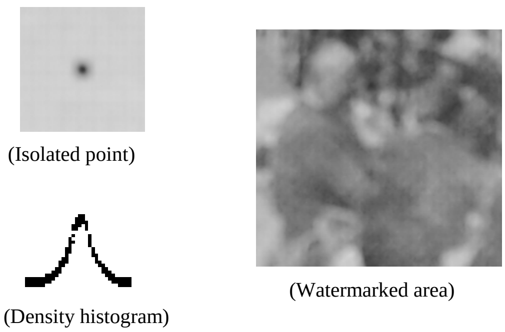

Fig. 3. (c) Part of magnified image and density histogram
(FWHM=8, DCT, DC=150, HC=15)

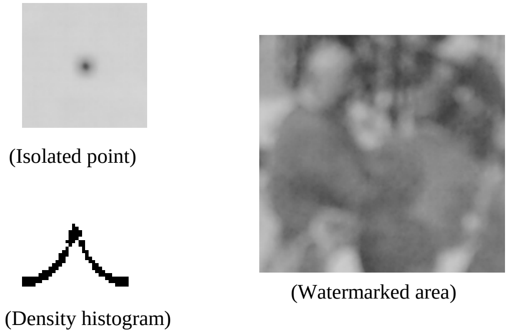

Fig. 3. (d) Part of magnified image and density histogram
(FWHM=11, DCT, DC=150, HC=15)

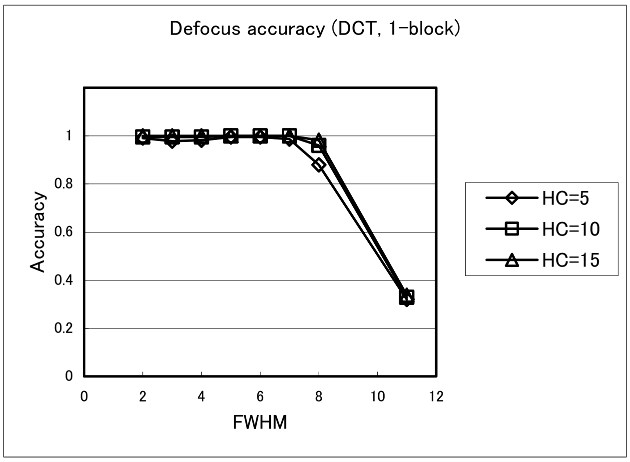

Fig. 4. (a) Accuracy under defocusing conditions
(DCT, 1-block method)

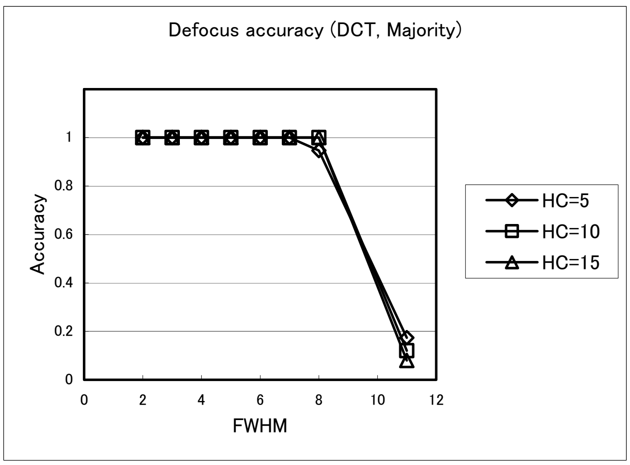

Fig. 4. (b) Accuracy under defocusing conditions
(DCT, Majority method)

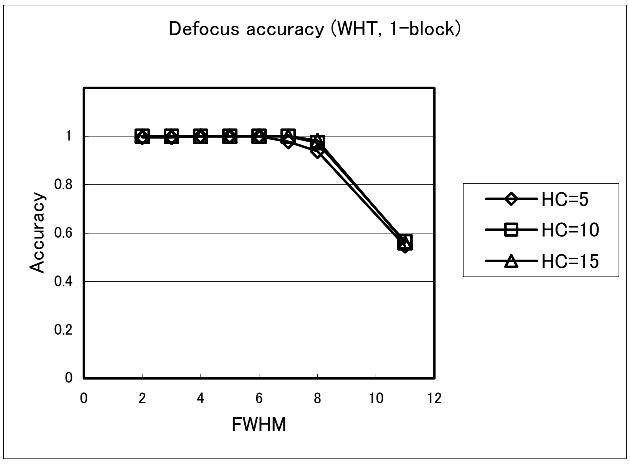

Fig. 4. (c) Accuracy under defocusing conditions (WHT, 1-block method)

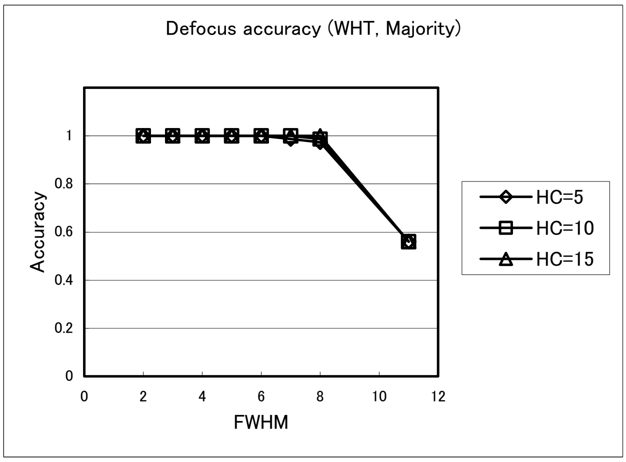

Fig. 4. (d) Accuracy under defocusing conditions (WHT, Majority method)

was acquired under all the HC values, according to the majority method using DCT and WHT. Moreover, the accuracy was near 100% when the 1-block method was used under the same conditions as those for the majority method. Although there was a tendency for the accuracy of detection to fall slightly when FWHM was eight pixels, the accuracy of detection was not less than 94% altogether according to the majority method. However, when FWHM was 11 pixels, the accuracy fell rapidly. A rapid decline in the accuracy of detection was expected from the tendency in Fig. 4 for FWHM for 9 and 10 pixels that were not measured in the experiments. From Fig. 3, we can see that the images of isolated points and the watermarked area have produced intense defocusing under the conditions of seven and eight pixels of FWHM. The experimental results revealed that almost 100% accuracy of detection could be obtained under such defocusing intensity. However, it is thought that the accuracy of detection deteriorates with defocusing of nine or more pixels of FWHM.

V. CONCLUSION

We evaluated degradation in the accuracy of detection that arises from defocusing of images when taking the photographic conditions into consideration that are not optimal assuming a practical-use environment of optical watermarking. We used the FWHM of a one-dimensional Gaussian function to measure defocusing that approximated LSF, and we measured the FWHM of isolated points and evaluated the accuracy with which watermarked images could be detected when the focal length of the digital camera was changed. As a result, when defocusing whose FWHM for the normalized one-dimensional Gaussian function was about eight pixels occurred, we found that the accuracy of detection was near 100% under conditions beyond HC=5. Compared with images that produced actual defocusing and the FWHM value, intense defocusing occurred in images at eight pixels of FWHM. We concluded from these results that optical watermarking has strong tolerance against image defocusing. The practicality of optical watermarking in a real-use environment was demonstrated with the robustness against geometric distortion we previously proposed.

REFERENCES

[1] 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.

[2] M. Hartung and M. Kutter, "Multimedia watermarking techniques", *Proc IEEE*, Vol.87, No.7, pp.1079-1107, 1999.

[3] J. Haitsma and T. Kalker, "A Watermarking Scheme for Digital Cinema", *ICIP2001*, vol.2, pp. 487-489, 2001.

[4] 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.

[5] 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.

[6] K. Uehira and M. Suzuki, "Digital watermarking technique using brightness-modulated light", *Proc. ICME2008*, pp. 257-260, 2008.

[7] Y. Tan, H. Liu, S. Huang, B. Sheng and Z. Pan, "An Optical Watermarking Solution for Color Personal Identification Pictures", *Proc. of SPIE2009*, Vol. 7512, 75120A, 2009.

[8] Y. Ishikawa, K. Uehira and K. Yanaka, "Practical evaluation of Illumination watermarking technique using orthogonal transforms", *IEEE/OSA J. Display Technology*, pp. 351-358, 2010.

[9] T. Yamada, S. Gohshi and I. Echizen, “Re-shooting prevention based on difference between sensory perceptions of humans and devices", *Proc. ICIP 2010*, Hong Kong, Sept. 2010.

[10] Y. Ishikawa, K. Uehira and K. Yanaka, "Optical watermarking technique robust to geometrical distortion in image", *Proc. ISSPIT2010*, pp.67-72, 2010.

[11] Y. Ishikawa, K. Uehira and K. Yanaka, " Robust Optical Watermarking Technique by Optimizing the Size of Pixel Blocks of Orthogonal Transforme", *Proc. IAS2011*, Oct. 2011.

[12] A. Rosenfeld and A. C. Kak, *Digital Picture Processing*, Academic Press, New York, 1976.