Embedding Watermarking into Real Object Image Data Using QR-code and Optical Watermarking Technique

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Abstract

We have proposed an "optical watermarking" technique that is a method of embedding watermarking information into image data taken from pictures of real objects by using spatially modulated illumination. A light source of the illumination that contains watermarks irradiates objects, and an image capturing device such as a digital camera is used to acquire watermarked image data. Arbitrary information can be embedded into the obtained image data to use it unconsciously as a method of telecommunication, as well as applying it to the security of image information as is done in copyright protection. We have examined a method of embedding Quick Response code (QR-code) information into real object images as invisible code information by using a discrete wavelet transform with optical watermarking. We clarified the relation of the volume of data on QR-code information that was able to be embedded under unit pixel counts to the accuracy of detecting embedded watermarking data, as the number of cells of QR-code was assumed to be changeable.

Keywords: digital watermarking, spatially modulated illumination, QR-code, discrete wavelet transform

Introduction

As the distribution of digital image content throughout the Internet or other media is rapidly increasing, techniques of digital watermarking have been widely recognized as methods of protecting the copyrights of image content [1]-[3]. For example, digital watermarking is embedded in digital data in advance to protect printed images [4][5]. However, this method cannot prevent images without digital watermarking from being illegally used, such as pictures in museums being photographed with digital cameras, because digital watermarking with this method has to be embedded before the image content itself is distributed.

We previously proposed a novel technology that could protect the copyright of images of objects that did not have watermarking [6][7]. This "optical watermarking" technique used illumination that invisibly contained the watermarking information. Using this technique the image data of a real object irradiated with such illumination also could contain watermarking information. The watermarking information from an image taken with a digital camera could be extracted by image processing. We used orthogonal transforms such as a Discrete Cosine Transform (DCT) or a Walsh-Hadamard Transform (WHT) as methods of embedding the watermarking. We also previously proposed techniques that were robust to various distortions due to the shooting and reflectance conditions of objects in practical cases [10]. Arbitrary information can be embedded unconsciously into the image data of real objects by using "optical watermarking" technology, which means the technology can be used as a method of telecommunication using illumination. Here, we propose a new technique of embedding code information using a discrete wavelet transform (DWT) and Quick Response code (QR-code). We also examine the relation between the volume of data for QR-code information and the accuracy of detection with the error collection capabilities of QR-code. We describe experiments and present results that demonstrate the feasibility of the new technology.

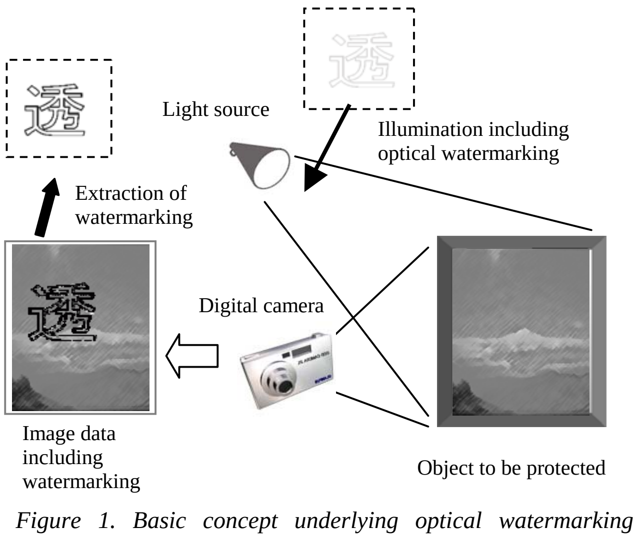

Figure 1. Basic concept underlying optical watermarking technology

Basic Technique for Producing Optical Watermarking

Figure 1 outlines the basic concept underlying the technology of optical watermarking. A light source that contains invisible information illuminates an object, and a digital camera is used to take a photograph of the object. As the illumination by the light source includes watermarking data, any photographed image of the object illumined with this light will also include watermarking. Watermarking information from this photographed image can be extracted in the same way as with the conventional watermarking technique by using image processing. A projector can be used as the light source, which provides a distribution of 2D-illumination, and the watermarking information is distributed in the form of this 2D-illumination. The spatial modulation in 2D-illumination has to be imperceptible to the human-visual system. Therefore, the brightness distribution given by the light source looks uniform to the observer over the object, which is the same as with conventional illumination. The brightness of the object's surface is proportional to the product of the reflectance of the object's surface and illumination by the light source.

The advantage of this technology is that the watermarking information can be added by light. Taking advantage of this, it can be applied to objects that are difficult to embed with conventional digital watermarking, such as pictures painted by famous artists. Watermarking information can also be easily rewritten in real time. Moreover, it is possible to apply it to 3D objects, such as sculptures, merchandise, and even the human body.

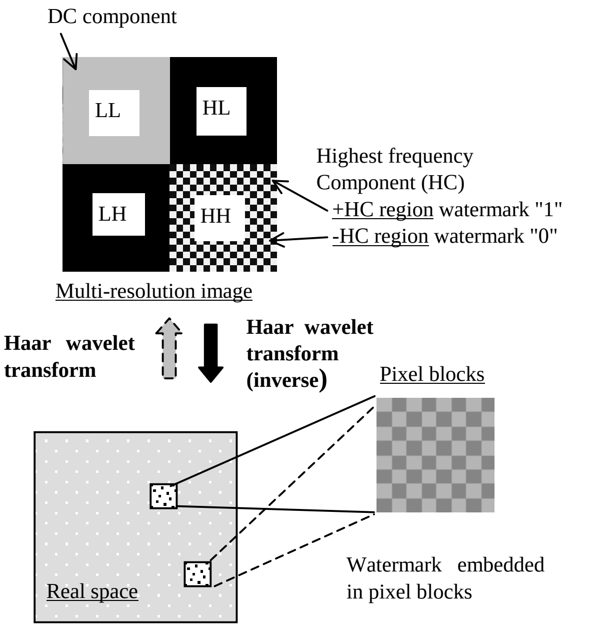

Figure 2. Producing watermarks using Haar wavelet transform

Figure 2 illustrates where a Discrete Wavelet Transform (DWT) has been used to produce watermarking images. A multi-resolution image is used to express the layer of frequency components. A DC value is given to the whole plane of the LL component image, and this gives an average brightness to the entire watermarking area. The highest frequency component (HC) value for the HH component image is provided to every $\frac{N}{2}\times\frac{N}{2}$ component block, and this yields the 1-bit binary information as watermarking data. The phase of HC is used to express binary data i.e., if the phase of HC is positive this is expressed as "0", otherwise it is expressed as "1". All component values for the LH component image and the HL component image are "0". With $\frac{M}{2}\times\frac{M}{2}$ pixels as the size of each component image, a watermarking image of $M\times M$ pixels is produced using an inverse DWT.

We used a Haar Wavelet Transform (Haar DWT) as the algorithm for the DWT. Figure 3 explains details on the Haar DWT. The original image of a 2×2 pixel block is converted by Haar DWT to a 2×2 component block, which consists of W_{LL}, W_{HL}, W_{LH}, and W_{HH}. Eqs. (1) and (2) give forward and inverse Haar DWT, which are simple linear equations.

$$\begin{aligned} w_{LL} &= \frac{1}{4}(a+b+c+d) \\ w_{HL} &= \frac{1}{4}(a-b+c-d) \\ w_{LH} &= \frac{1}{4}(a+b-c-d) \\ w_{HH} &= \frac{1}{4}(a-b-c+d) \end{aligned} \tag{1}$$

$$\begin{aligned} a &= w_{LL}+w_{HL}+w_{LH}+w_{HH} \\ b &= w_{LL}-w_{HL}+w_{LH}-w_{HH} \\ c &= w_{LL}+w_{HL}-w_{LH}-w_{HH} \\ d &= w_{LL}-w_{HL}-w_{LH}+w_{HH} \end{aligned} \tag{2}$$

Watermarking image data generated by Haar DWT become equivalent watermarking image data generated by WHT with the same DC and HC values.

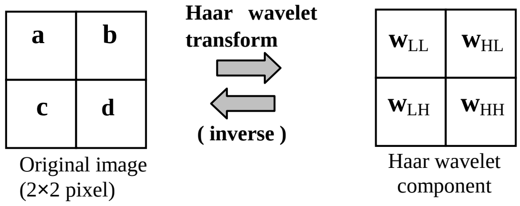

Figure 3. Algorithm for Haar wavelet transform

Experiments

We used QR-code in the experiments as the method of embedding code information with optical watermarking. QR-code has image data that basically consist of binary pixels, and each of them is called a "cell" in the specifications for the QR-code standards. The image data of QR-code were embedded into an HH component image of multi-resolution images of Haar DWT. Each cell of QR-code was equivalent to $\frac{N}{2}\times\frac{N}{2}$ component blocks of the HH component image, as the white cells were assigned binary "1" and the black cells were assigned binary "0". Then, watermarking image data were produced with the method described in the previous section.

Various "versions" are available in the specifications for QR-code according to the capabilities of the volume for embedding data. Error correction capabilities are also specified with Reed-Solomon coding. We intended to evaluate the accuracy of decoding QR-code with the capabilities of error correction code, in the defined volume of code information on QR-code. We used three versions of the QR-code specifications in the experiments. Table 1 summarized details on the specifications of the three versions used in these experiments. An HH component image was produced as sufficient margins were added to the surrounding space of the QR-code image, which are listed in Table 1. A DC value was given to the LL component image, and a value of "0" was given to the HL and LH component images. With all component images, the optical watermarking images were created using inverse Haar DWT.

A Digital Light Processing (DLP) projector with a resolution of 800×600 pixels was used as the light source. Printed A4 images of the standard image data were used for the objects. The value for DC was fixed at 150, and the values for HC were varied as the experimental parameters. The size of the projected watermarking area was about 200×200 mm on the object image, which was about 1300×1300 pixels when taken with a digital camera with a resolution of 4288×2848 pixels. Figure 4 has the magnified image of a part of the object embedded with watermarking.

Table 1. Specifications for QR-code in Experiments.

Version	Ver.3	Ver.5	Ver.10
cell (*1)	29	37	57
charactor (*2)	24 bytes	44 bytes	119 bytes
error (*3)	30%	30%	30%
pixel/cell	4×4pel	3×3pel	2×2pel
pixel/code	116×116pel	111×111pel	114×114pel
added cell Left/top Right/bottom	3 (total) 2 1	5 (total) 3 2	7 (total) 4 3
pixel/water-marking area	128×128pel	126×126pel	128×128pel

(*1) No. of code units of QR-code
(*2) No. of embedded charactors into QR-code
(*3) Maximum error correction ability

Figure 4. Part of Object Image Embedded with Optical Watermarking (HC=15, Ver.5)

A watermarked area was clipped out from the captured image data that was brighter than its neighbors. The pixel size of the watermarking area was transformed to the sizes described in Table 1 for the versions used to encode QR-code. Then, forward Haar DWT was carried out on the entire watermarking area. A multi-resolution image was obtained, and the HH component image was separated from this multi-resolution image. If the embedded watermarking information was correctly read out, a +HC value or -HC value appeared on every $\frac{N}{2}\times\frac{N}{2}$ component block of the HH component image. However, if the spatial-frequency component of the object image contained an HH frequency element, the coefficients in an $\frac{N}{2}\times\frac{N}{2}$ component block may be disrupted by noise derived from this element. We therefore used the following procedure to read out the embedded watermarking data. First, the mean value of all coefficients of every $\frac{N}{2}\times\frac{N}{2}$ component block in the HH component image was calculated, where 1-bit binary information was embedded, and the calculated mean value was evaluated. If the phase of the mean value we obtained was negative, the watermarking information that was read out was determined to be "0"; otherwise, it was determined to be "1". Then, the value of each cell of the QR-code was restored according to the binary information that was read out. If the determined value was "0", the cell was assumed to be black, and if it was "1", the cell was assumed to be white. As a result, the QR-code image was reproduced. All the blank parts in the reproduced image data were replaced with a white

(a) Ver.3 (b) Ver.5

(c) Ver.10

Figure 5. Restored QR-code (HC=5)

pixel according to Table 1. QR-code reader software [11] was used to decode the reproduced QR-code. The error correction rate was also recorded when decoding was possible.

Results and Discussion

Figure 5 has examples of the restored QR-code that were embedded with optical watermarking under the condition of HC=5. Numerous error cells can be seen in the blank and the "position detection pattern" parts, especially at the top and right. However, the embedded code information in these examples was correctly decoded by the error correction capabilities of QR-code. Table 2 summarizes the results that present the error rate for decoding by each version of QR-code in the experiments under conditions of HC=5, 7, 10, 15, 20, and 25. That is, embedded code information could be decoded under all conditions in Table2 with the maximum error correction capabilities of "level H" (which had 30% possibility of error correction) in generation of QR-code.

When the HC values increase in Table 2, they tend to monotonically decrease to smaller error rates for each version, although a reversal can be seen in a part of the HC values. Moreover, with later versions, the error rates tend to increase, although the results for HC=25 of Ver.5 and Ver.10 are reversed. The amount of information able to be embedded into QR-code and the error rate of decoding were found to be a trade-off from these experiments. The inversion phenomenon found in the error rates may have originated from the non-linearity of the DLP projector we used in the experiments.

Table 2. Error Rate of Read out QR-code.

HC	Version		
	Ver.3 (cell:29)	Ver.5 (cell:37)	Ver.10 (cell:57)
5	2.9%	15.7%	22.3%
7	2.9%	11.2%	14.5%
10	0%	6.7%	6.9%
15	1.4%	3.0%	8.7%
20	0%	3.0%	4.0%
25	0%	3.0%	2.3%

Conclusion

We found that there was a relation of the volume of data for QR-code information that was able to be embedded under unit pixel counts to the detection accuracy of embedded optical watermarking data. We evaluated the error rate of decoding QR-code by changing the QR-code size embedded under the same area as the optical watermarking image. As a result, the error rate decreased if the size of QR-code that was embedded was reduced to the same area (i.e., if the embedded amount of code information was small), and we found that the volume of code information to be embedded and the error rate was a trade-off. We also evaluated the relation between the strength of embedding optical watermarking and the error rate, and found that this was also a trade-off. The inversion phenomenon in the error rate to the volume of code information to be embedded in the unit area, and the error rate to the strength of embedding optical watermarking will be clarified in future work.

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Biography

Yasunori Ishikawa received his B.S. in measurement and instrumentation engineering from the University of Tokyo, Japan, in 1977 and Ph.D. in information engineering from Kanagawa Institute of Technology, Japan, in 2011. He worked for Fuji Electric Corporation and Ricoh Corporation from 1977 to 2001, where his work involved the research and development of embedded systems for consumer products, image processing and communication products, and research on image compression. Since 2001, he has been the president of YIT Consulting Corporation, offering technical consulting and technology transfer in his fields of expertise.

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 in Osaka, Japan. He joined NTT Electrical Communication Laboratories in Tokyo, Japan, in 1981. Since then, he has been engaged in the research and development of image acquisition technologies, display systems, and high-reality video communication systems. In 2001, he joined Kanagawa Institute of Technology as a professor and is currently engaged in research on 3-D displays and optical watermarking.

Kazuhisa Yanaka received his B.S., M.S., and D.E. from the University of Tokyo in 1977, 1979, and 1982. He joined NTT Electrical Communication Laboratories in Tokyo, Japan, in 1982. He joined Kanagawa Institute of Technology in 1997, where he is currently a professor. For more than 30 years, he has been researching various aspects of images such as image processing, image communication, image input/output systems, and optical watermarking.