A Technique of Time Domain Sequential Data Embedding into Real Object Image Using Spatially Modulated Illumination

Yasunori ISHIKAWA Kazutake UEHIRA

Kazuhisa YANAKA

Kanagawa Institute of Technology
Atsugi-shi, Kanagawa, Japan
yasu@yit-pe.com

***Abstract* -- We propose a new technique that uses spatially modulated illumination for embedding time domain sequential data into moving picture data. This is based on the "optical watermarking" technology that can be applied to protect "analog" objects like pictures painted by artists from having photographs taken of them illegally. Another important application of optical watermarking is embedding real time data sequence into real object images unconsciously, which may be moving pictures. We carried out experiments that sequential watermarking image data that had 10 fps (frame per second) were irradiated onto objects with projector, and moving image data with the picture rate of 30 fps were taken with a video camera. The result was that the embedded sequential watermarking information could be detected accurately from the obtained moving image data. In the experiments we embedded 256 bit information into watermarking image area of each frame that had the image size of 128 x 128 pixels, that is, the bit-rate of embedding information was 2.5kbps. The experimental results indicate that faster bit-rate and improved detection accuracy may be achieved when lager size of the area of embedding watermarks and higher resolution image for each frame are used.**

***Keywords*—Digital watermarking, Optical watermarking, Spatially modulated light, Copyright protection**

I. INTRODUCTION

The importance of techniques of digital watermarking have recently been widely recognized, because the rapid growth of Internet technology has increased the circulation of digital content such as that in image information. Digital image data can easily be created in desktop environments with personal computers and peripheral image devices such as image scanners or digital cameras, and they can easily be copied without any image degradation, as the content data are digital. Protecting the copyright of image information has become a pressing issue in these environments. Where conventional watermarking technology has been applied to printed objects, digital watermarking has been embedded into the image data before the images have been printed. This technology has prevented images from being illegally photographed with digital cameras or copied with scanners. However, this method cannot protect "analog" images, such as pictures that have been painted by artists, from being illegally captured with digital cameras or cellular phones [1]-[5].

We proposed a technology that could prevent images of objects that did not have watermarking from being illegally used [6]. We used illumination that invisibly contained the watermarking generated by a Discrete Cosine Transform (DCT). When the illumination containing watermarking was projected onto an object, any image of the object taken with a digital camera also contained watermarking and this could be extracted by image processing. We used a Walsh-Hadamard

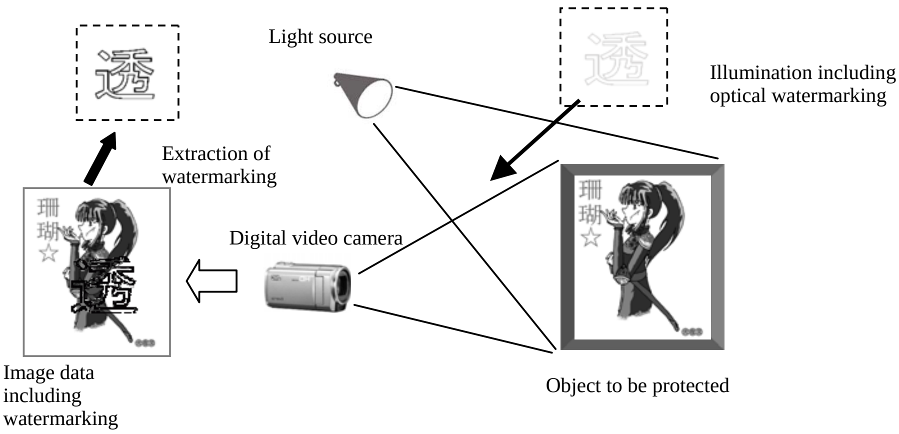


Fig. 1. Basic concept underlying optical watermarking technology

Transform (WHT) as well as DCT as techniques of embedding the watermarking [7]. Furthermore, we demonstrated that the technology could be applied to real 3D objects (cubic objects) [8]. However, these papers reported that the technology was only used for still pictures. Narasimhan et al. found that a method of structured light-based "temporal dithering" could control the intensity of pixels on the time scale of microseconds (μsec) using a Digital Light Processing (DLP) projector and high-speed camera, although it could not easily be applied to ordinary moving picture data [9]. We describe the application of optical watermarking technology to moving picture images in this paper and present results that demonstrate the practical feasibility of the technology being applied to moving picture images.

II. BASIC TECHNIQUE OF OPTICAL WATERMARKING

Fig. 1 outlines the basic concept underlying the technology of optical watermarking, where an object is illuminated by light that contains invisible information. As the illumination includes watermarking data, any photographed image of the object illumined with this lighting will also include watermarking. By digitizing this photographed image, watermarking information can be extracted in the same way as with the conventional watermarking technique. The light source provides a distribution of 2D-illumination like that with a projector, and the watermarking data are expressed in the form of this 2D-illumination distribution. However, the spatial modulation in illumination has to be imperceptible to the human-visual system. The brightness distribution given by this light source then looks uniform to the observer over the object, the same as that 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 incident light.

The main attribute of the technology is that the watermarking can be added by light. Therefore, it can be applied to objects that cannot be electronically embedded with conventional watermarking, such as paintings created by renowned artists. Moreover, it offers the possibility of being applied to 3D objects, such as sculptures, merchandise, and even the human body, as well as being applied to 2D objects.

Fig. 2 outlines the procedure for watermarking where the watermarking area consists of numerous blocks and each is 16×16 or 8×8 pixels. The average brightness of all blocks is expressed as a DC component in frequency space, which gives an average brightness for the entire area for watermarking, i.e., the brightness of illumination. Also, every block in frequency space has the highest frequency component (HC) in both the x - and y -directions, which express the 1-bit binary information used for watermarking. The phase of HC is used to express binary data, i.e., "0" or "1". If the sign of HC in a block is positive, this is assumed to be expressed as "1", and if the phase is

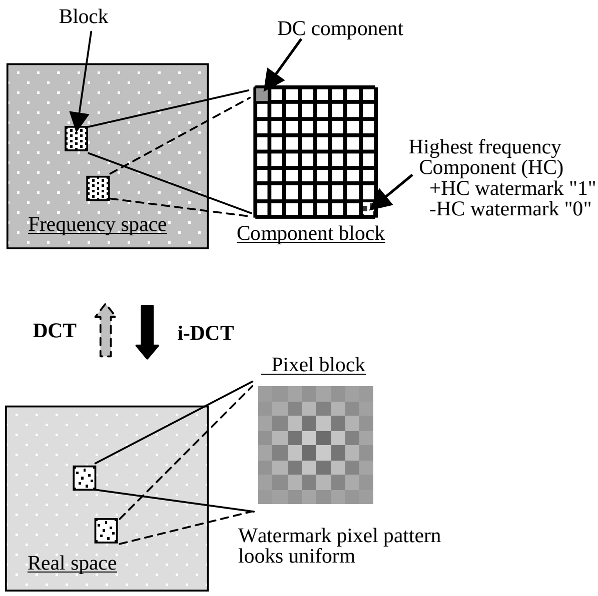


Fig. 2. Producing watermarks using DCT

opposite to this (i.e., minus), this is assumed to be expressed as "0".

We used 2D inverse DCT (i-DCT) to generate the watermarking image, which is expressed by

$$f_{i,j}(x,y) = \sum_{u}^{N-1}\sum_{v}^{N-1} C(u)C(v)F_{i,j}(u,v) \bullet \cos\{\frac{(2x+1)u\pi}{2N}\}\cos\{\frac{(2y+1)v\pi}{2N}\} \qquad (1)$$

where $f_{i,j}(x,y)$ are the watermarking image data for pixel (x,y) of block (i,j) in real space, $F_{i,j}(u,v)$ are the data for component (u,v) of block (i,j) in frequency space, and N is the number of pixels in the block in the x- and y-directions. Here, $C(u)$ and $C(v)$ are given as

$$C(u) = \begin{cases} 1 & (u=0) \\ \sqrt{2} & (u \neq 0) \end{cases}, \qquad C(v) = \begin{cases} 1 & (v=0) \\ \sqrt{2} & (v \neq 0) \end{cases}$$

The $F_{i,j}(u,v)$ we used in these experiments is given as

$$F_{i,j}(0,0) = \mathrm{DC} \qquad (2)$$

$$F_{i,j}(N-1,N-1) =$$

$$\begin{cases} \text{HC, if binary data to be embedded in block } (i,j) \text{ are "1"} \\ \text{-HC, if binary data to be embedded in block } (i,j) \text{ are "0"} \end{cases} \qquad (3)$$

$$F_{i,j}(u,v) = 0 \quad (\text{for } u,v \neq 0, \text{ N-1}). \qquad (4)$$

Eqs. (2)-(4) indicate that the formed image only has a DC component (the brightness of illumination) and a HC (the highest frequency component), and the other components are set to "0". Therefore, when the produced image was beamed onto the object with a projector, the embedded watermarking image could scarcely be seen by the human-visual system and it could also easily be read out from the object image.

Because the frequency components of the object image itself were lower than the HC, the embedded information for watermarking was easily separated from the object image.

III. EXPERIMENTS

We carried out experiments on embedding time-domain sequential data using the optical watermarking technique. The experiments focused on whether watermarking could be efficiently detected in the sequential digital images taken with digital video cameras, under conditions where it had to be sufficiently small to be invisible on the object.

Watermarking images of all frames in the time domain sequential data were produced that consisted of 16 × 16 blocks in this experiment, where each block had 8 × 8 pixels, i.e., the watermarking images had 128 × 128 pixels. Fig. 3 has part of a magnified image of watermarking. Binary watermarking information was embedded as blocks of "0" and "1" that were alternately positioned in a checkerboard pattern. We created sequential data for these watermarking images. Fig. 4 contains the detailed structure of the data we created that has a sequence of 10 fps (frame/sec) for moving picture data. When this moving picture data were input into the projector, "Even pattern frame" and "Odd pattern frame" were alternately displayed on the object every 1/10 sec. Fig. 5 helps to explain the embedded watermarking pattern for "Even" and "Odd" pattern frames. We then took a moving picture with a digital video camera, where MPEG-2 compressed digital video data were obtained. The video data we obtained were converted to sequential still image data of 30 fps, and embedded watermarking information was extracted from each separated frame. Fig. 4 also presents the timing between projected image data and the image data we obtained. As these were not synchronized in the time domain, one out of three consecutive frames of the obtained image data did not correctly capture the projected frame. We used the frame in the three consecutive frames that had the best detection rate to evaluate the accuracy of detection.

A DLP projector with a resolution of 800 × 600 pixels was used as a light source. Printed A4 images of the standard image data were used as the objects. We fixed the value for DC to 150 and changed HC, which were the experimental parameters. The HC value controlled the strength of embedded watermarking. The projected watermarking area was about 105 × 105 mm on the object image, which was equivalent to about 300 × 300 pixels taken with a digital video camera that had a resolution of 720 × 480 pixels.

The watermarking area illuminated with the projector on the object was almost an exact rectangle in these experiments, because the shape of the image irradiated on the object plane was automatically corrected with the projector. However, as the digital video camera was handheld by the operator, the images of pictures taken under such conditions were almost all distorted from their rectangular shape. To obtain precise rectangles of the watermarking area, distorted images taken with the digital video camera were corrected with the following method. The irradiated region of optical watermarking was considered to be quadrilateral, which was created with four corner points in this region. We corrected this as the entire area might have become a precise square. Transformation from an undistorted coordinate system (x, y) to a geometrically distorted system (x', y') is generally expressed with two equations.

$$x' = h_1(x, y), \quad y' = h_2(x, y) \qquad (5)$$

If the distortion is perspective, transformation is expressed with two linear equations.

$$x' = ax + by + d, \quad y' = dx + ey + f \qquad (6)$$

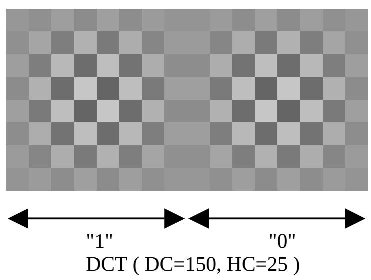


Fig. 3. Part of magnified image of watermarking

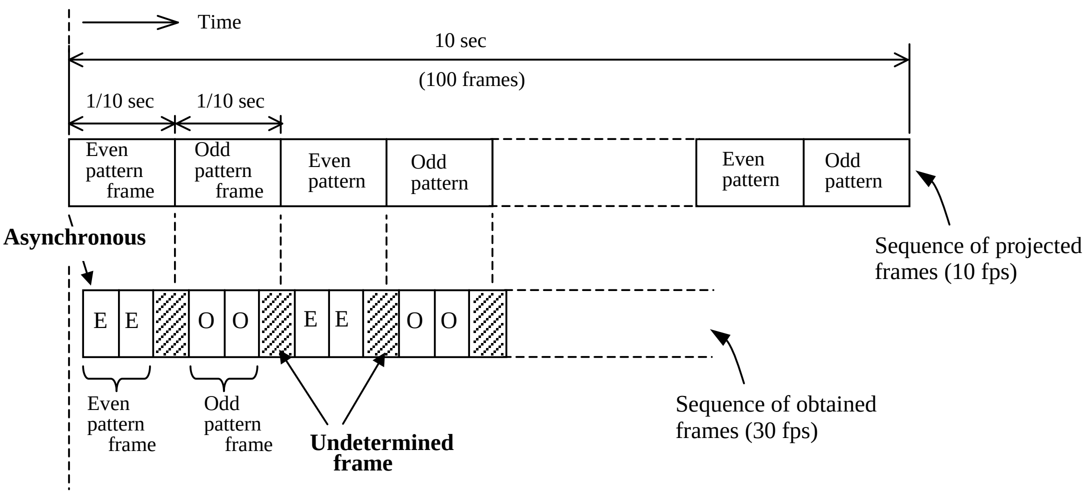
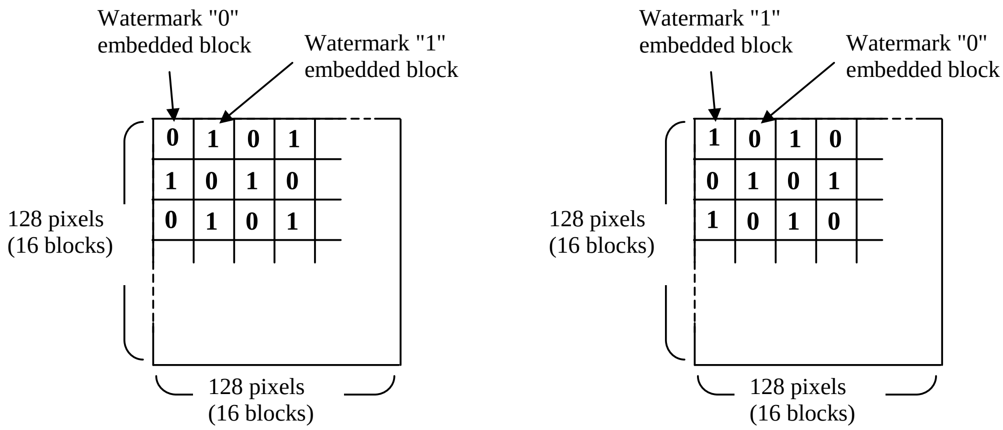


Fig. 4. Sequence of projected and obtained frames



(a) Even pattern frame (b) Odd pattern frame

Fig. 5. Embedded watermarking pattern of each frame

When the coordinates of all corner points of a quadrangle are given, the coefficients of the linear expression above can be determined from three of these and the corresponding coordinates of the original undistorted rectangle. The value of pixels in the distorted quadrangle can be transformed to the value of pixels in the undistorted rectangle by using these equations. However, because the coordinates of the transformed pixels do not generally become integers, an interpolation technique is utilized to determine the density value of the nearest pixel. Linear transformation using the four nearest neighboring pixels was used in these experiments, which is the so-called "bi-linear interpolation".

Then, the corrected rectangular domain was clipped out as the watermarking area. The resolution of the clipped rectangle was then transformed to just 256 × 256 pixels, and it was divided into 16 × 16 blocks, each of which had 16 × 16 pixels. We carried out DCT on all blocks using Eq. (7).

$$F_{i,j}(u,v) = \frac{C(u)C(v)}{M \times M} \sum_{x}^{M-1} \sum_{y}^{M-1} f_{i,j}(x,y) \bullet \cos\{\frac{(2x+1)u\pi}{2M}\} \cos\{\frac{(2y+1)v\pi}{2M}\} \quad (7)$$

Here, $C(u)$ and $C(v)$ are the same as those in Eq. (1).

The accuracy with which the embedded data of each frame were read out was evaluated by checking the sign of the $F_{i,j}(7,7)$ components for all blocks. Two methods of embedding the data were used. The "1-block method" involved embedding 1-bit data into one block and embedding 256 1-bit binary data into 16 × 16 blocks. The "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 distance between the blocks was set to five and 75 1-bit binary data were embedded in 16 × 16 blocks in the experiments.

The accuracy with which embedded watermarking information was detected from the entire moving picture data was evaluated by using the detection rate for each frame cut out from the digital video data we obtained. That is, the detection rates for three consecutive frames were compared, and the frame that had the best detection rate for these consecutive frames was used. The average accuracy of detection for the whole sequence of watermarking images was found by using the mean value for the detection rates of watermarking information for all 100 frames that formed the moving picture data, as shown in Fig. 5.

IV. Results and Discussion

Fig. 6 gives the average accuracy with which embedded watermarking information was detected from the moving picture data. The accuracy of detection reached 100% for HC=10 and over with the majority method, and this was almost 100% for the same HC value when the 1-block method was used. However, under conditions of HC=5 and 7, the accuracy of detection was under 90% in both cases when the 1-block and majority method were used. We achieved almost 2.5 kbps using the watermarking image size of 128 × 128 pixels for each frame, when the 1-block method was used.

The detection rate for embedded watermarking information depended on the resolution of image data. The resolution of the watermarking area extracted from the video data was about 300 x 300 pixels in the experiments, which might not be enough to make detection more accurate. We also have to consider other distortion factors such as motion blurring and defocusing that could affect accuracy. Higher resolution video may reduce these problems.

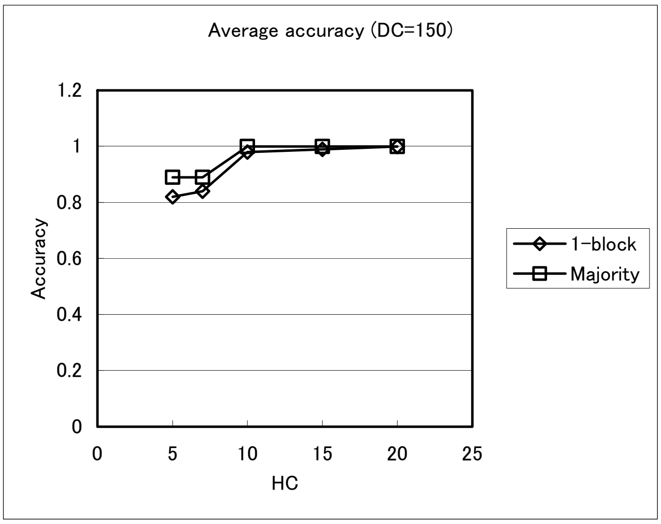


Fig. 6. Average detection accuracy of watermarking

V. CONCLUSION

We proposed a new technique of embedding sequential watermarking information into moving picture data that were taken of real objects, using optical watermarking technology with spatially modulated illumination. This technology can basically be applied to protect "analog" objects like pictures in museums from having photographs of them taken illegally. We introduced another application of optical watermarking in this paper to embed real-time data sequences into real object images that could not consciously be perceived, which could be applied to motion image data.

The experimental results revealed that, when sequential watermarking image data of 10 fps were projected onto an object and moving image data with a picture rate of 30 fps were taken with a digital video camera, 2.5 Kbps of watermarking information could be embedded into video data with sufficient accuracy of detection. When a larger embedding watermarking area is used for frames in the sequence of projected images and/or higher resolution and higher image quality are used for taking video data, faster bit rates and improved accuracy of detection may be obtained. We intend to verify these hypotheses in future experiments.

REFERENCES

[1] I. J. Cox, J. Kilian, F. T. Leighton and T. Shamoon. Secure spread spectrum watermarking for multimedia. IEEE Trans. Image Processing, 6 (12): 1673-1687, 1997.
[2] J. Haitsma and T. Kalker. A Watermarking Scheme for Digital Cinema. Proc. ICIP 2001, 2: 487-489, 2001.
[3] M. Ejima and A. Miyazaki. Digital watermark technique for hard copy image. Trans. IEICE (A), J85-A (4): 451-459, 2002.
[4] 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: 1099–1107, 2005
[5] Z.Liu. New trends and challenges in digital watermarking technology: Application for printed materials. Multimedia Watermarking Techniques and Applications, Auerbach Publications: 289-305, 2006.
[6] K. Uehira and M. Suzuki. Digital watermarking technique using brightness-modulated light. Proc. ICME2008: 257-260, 2008.
[7] Y. Ishikawa, K. Uehira and K. Yanaka. Practical evaluation of Illumination watermarking technique using orthogonal transforms. J. Display Technology, 6 (9): 351-358, 2010.
[8] Y. Ishikawa, K. Uehira and K. Yanaka. Protection of 3D objects against illegal photography using optical watermarking technique with spatially modulated illumination. Proc. IMAGAPP2011: 49-52, 2011.
[9] S. G. Narasimhan, S. J. Koppal, and S. Yamazaki. Temporal Dithering of Illumination for Fast Active Vision. Proc. E CCV: 830-844, 2008.