Improvement on Information Capacity of Watermarked Images by Using Multi-Valued Area of Embedded Signals

Takahiko Horiuchi[†*], Masahiro Wada[†], Ryoichi Saito[†] and Shoji Tominaga[†]
[†]Chiba University, Yayoi-cho 1-33, Inage-ku, Chiba 263-8522 Japan
[*]E-mail: horiuchi@faculty.chiba-u.jp Tel/Fax: +81-43-290-3485

Abstract— **Digital watermarking technology is very useful as a service for embedding ID data to analog content such as an image on printed material. Recently, many algorithms have been proposed for detecting watermarks from a captured image by a camera-equipped cellular phone. This paper focuses on an approach to embedding the ID data in a frequency domain. Although the approach has an advantage of robustness against a partial distortion of the captured image, the previous method along the approach has the problem of low limitation of embedded information capacity. This paper proposes a watermarking method for improving embedded information capacity by using multi-valued area of signals instead of binary signals. The feasibility of the proposed algorithm is confirmed in experiments using actual printed images.**

I. Introduction

In recent years, a digital color camera is installed in a standard cellular phone. QR Codes shown in Fig. 1 are now used in a much broader context, including both commercial tracking applications and convenience-oriented applications aimed at cellular phone users. The QR Codes are common in Japan, where they are currently the most popular type of two dimensional barcodes. The QR Codes storing addresses and URLs may appear in magazines, on signs and business cards. Users with the camera phone can scan the image of the QR Code causing the phone's browser to launch and redirect to the programmed URL. However, there is the disadvantage that the space to print the special pattern is necessary for the QR codes. Moreover, the unpleasant pattern destroys the design and the layout of documents.

Recent technologies for digital watermarking enable to link the key information embedded invisibly in printed photographs to related website on the Internet [1]-[3]. The watermark contains a URL which directs the user to a specified wabpage as shown in Fig. 2. Thus the watermark works as a bridge from printed media to the Internet webpage. In [4] and [5], various problems demanded from the technique are discussed, and the robustness to various changes for taking a picture is investigated.

In this study, we focus on the frequency domain approach in [3], which has the robustness against the distortion of the captured image and illumination variation. However, the information capacity of watermarked images was smaller than the other approaches [1],[2].

Fig. 1 Examples of QR codes.

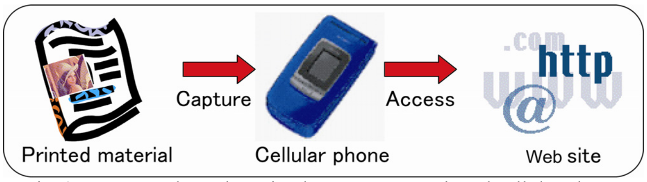

Fig. 2 Watermark ID detection by a camera-equipped cellular phone.

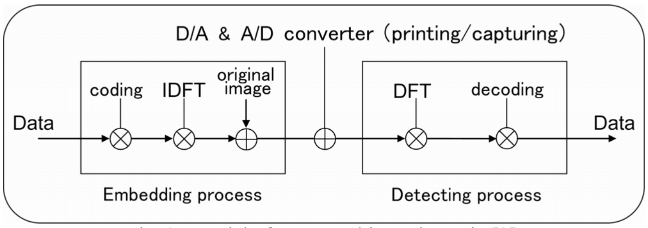

Fig. 3 Model of watermarking scheme in [3].

This paper aims to improve the embedded information capacity in the frequency domain approach. In general signal processing approach, an old trick for improving the data capacity is to use the multi-valued signal strength. However, appropriate setting of the multi-valued signal strength was difficult in steady signal detection from the captured images. This paper proposes a watermarking method for improving embedded information capacity by using multi-valued area of signals.

II. Frequency Domain Approach and Its Problem

Figure 3 shows a model of the watermarking scheme in [3]. The digital-to-analog (D/A) and analog-to-digital (A/D) conversion are generally included in the scheme. Capturing images on analog media using a cellular phone camera introduces distortion caused by D/A conversion, such as degradation due to printing, and A/D conversion such as perspective distortion due to the capturing angle. The frequency domain approach embeds information as a binary signal pattern in the frequency domain. Since the embedded information is distributed in the image space, the frequency domain approach is robust against the distortion of the image and the noise caused by the D/A and A/D conversions. In this section, the outline of the frequency domain approach in [3] is briefly explained, and the problem is clarified.

A. Watermark Embedding Process

(1) Signal pattern construction

The watermark embedding process is shown in Fig.4. At first, the watermark ID is expressed as a binary signal pattern in the frequency domain (Fig. 4-a). This signal pattern consists of five concentric circles. In these circles, two circles of the outside are used to adjust the position and alignment, and three circles of the inside are used for expressing the ID information. The information is distinguished in order of the sequence of "1" and "0" on each circumference, and the data capacity depends on the number of the binary sequence.

(2) Watermark construction

The signal pattern in the frequency domain can be transformed into the IDFT pattern by the inverse discrete Fourier transform (Fig. 4-b). In general, the components of the IDFT pattern are real numbers. The watermark pattern as shown in Fig. 4-c is constructed by binarizing the IDFT components into $\{-a, a\}$. This binarization can keep the accuracy of the watermark pattern through the A/D and D/A conversions.

(3) Embedding to image

The watermark pattern is superimposed on an original color image in Fig. 4-d. When a pixel value exceeds the dynamic range, the simple clipping is performed. The digital watermark is embedded only in the Blue channel of the image because the Blue channel is less visible based on the human perceptual characteristics (Fig. 4-e). The embedding strength is modulated by the binarizing parameter a. The watermarked image is generated and the image is output into an analog medium, for example, by printing it.

B. Detection Process

(1) Detection of signal pattern

The operation flow for watermark detection is shown in Fig. 5. For the captured image in Fig. 5-a, the discrete Fourier transform (DFT) is performed. As shown in Fig. 5-b, the signal in the frequency domain consists of the embedded ID information and the original image. However, most frequency components of natural images are biased to the low frequency components. Therefore, the digital watermark embedded without the low frequency can be detected.

(2) Extraction of ID data

After adjusting the position and alignment using the outer two circles, the embedded position can be identified. By comparing with the intensity of the embedded signals, each signal is classified into "1" or "0". The ID is decrypted by judging the order of "1" and "0". When using the method in [3], we can embed only 10,080 ID data. The data capacity is too small in comparing with other approaches. The improvement of the capacity remains as a future work.

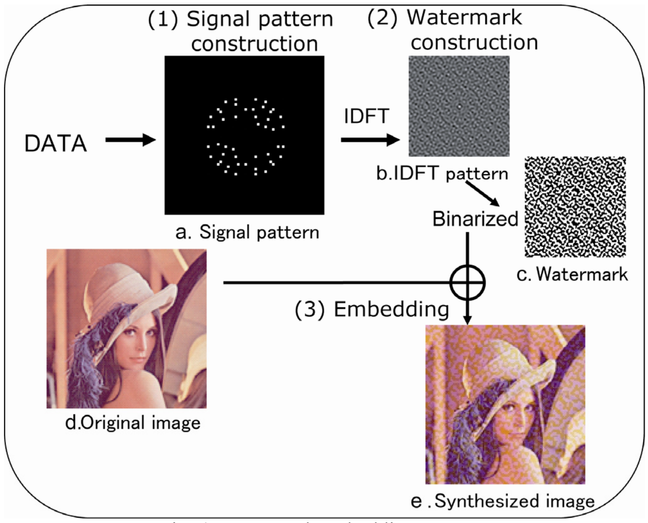

Fig. 4 Watermark embedding process.

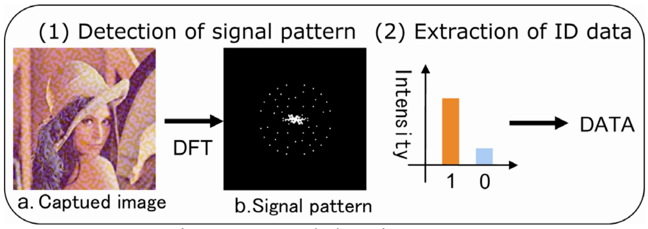

Fig. 5 Watermark detection process.

III. PROPOSED ALGORITHM FOR IMPROVING DATA CAPACITY

The data capacity may be improved easily by increasing the number of signals in the frequency domain. However, the space for increasing the signal is limited in the frequency domain. Note that only increasing the number of signals does not necessarily lead to improving the data capacity. This paper solves the problem by making multi-valued signals in the frequency domain.

A. Multi-Valued Intensity

In the signal processing field, the improvement of data capacity is often tried by making the multi-valued signal strength. This approach corresponds to making the multi-valued intensity pattern in the frequency domain. For a simple explanation, we consider three-level values. For three-level pattern in 8bit signal, signals A, B and N correspond to the values 255, 255(α/100) and 0, respectively. The parameter $\alpha \in [0,100](\%)$ means the compression rate of the intensity for signal B. Those signals are classified by using the detected signal intensity. Therefore, the intensity difference between signals B and N (BN difference), and between signals A and B (AB difference) becomes important for accurately classifying the three values.

Figure 6 shows experimental results of AB difference and BN difference for standard images "Baboon" and "Lena" in Fig. 13 by changing the parameter α. The intersection part between AB and BN differences shows the well-balanced part for the parameter α. As shown in Fig.6, the slope of both graphs is large. This means the detection accuracy deteriorates greatly by a small change of α. However, it is difficult to set a constant value appropriately according to the image, because the appropriate α depends on the images. Moreover, steady detection is difficult by using only the multi-valued intensity because the appropriate α also changes by the printing environment and the captured environment.

B. Multi-Valued Area

This paper newly introduces the multi-valued area for embedding signals. Let us consider a simple example of three-value pattern as shown in Fig. 7. We embed three types of signals in the frequency domain. Although there are many variations for making signal B, 13 to 16 pixels were suitable in our experiments. By using the same pattern in [3], the data capacity can be improved from 10,080 to 756,000. Moreover, in the case that the numbers of signals A, B, and N are the same, the information capacity becomes the most efficient. By adding six signals to the original pattern in [3], as shown in Fig. 8, the information capacity can be improved up to 18,711,000. Even if the same pattern in Fig. 8 is used as binary pattern, the data capacity is only 55,440. Thus, the proposed multi-valued technique can efficiently increase the capacity compared with an increase of the number of signals.

The IDFT pattern is generated by the IDFT. Figure 9 shows the principle of the proposed algorithm. As shown in the figure, the frequency power becomes strong for the signal with large area. As shown in the previous section, the power is binarized as $\{-a, a\}$. Here $2a < 255$ in the case of 8bit signals. If the frequency power exceeds 255, the dynamic range compression is performed as shown in Fig. 9. At this time, higher compression is required for signal with larger area. This compression causes the decrease of the value in signal B by the DFT as shown in Fig. 9. Then a power difference between signals A and B occurs clearly after the DFT, and the distinction of signals becomes possible.

C. Combination between Multi-valued intensity and area

By combining two multi-valued approaches described in the above subsections *A* and *B*, steadier detection becomes possible. Figure 10 shows experimental results of AB difference and BN difference for multi-valued area signals by changing the parameter α. By comparing with Fig. 6, the slope is gentle. This means that this approach is robust for changing the parameter α.

In the restored signal for three-value pattern, a high value is obtained in order of signals A, B and N. As mentioned above, total number of signals A, B and N is evenly provided. Therefore, $3P$-th restored signal is sorted, and P signals with higher power is classified into signal A. Signals from P+1 to $2P$ are classified into signal B, and the other signals are classified into signal N. The classification algorithm is summarized in Fig.11.

IV. EXPERIMENTS

In our experiments, we constructed ID patterns with 512×512 pixels. The size of signal B was 13 pixels and α=30

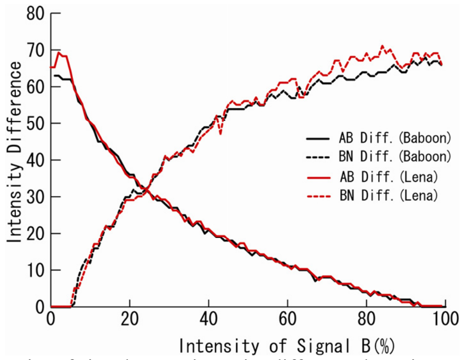

Fig. 6 Intensity of signal B v.s. intensity difference by using multi-valued intensity signals.

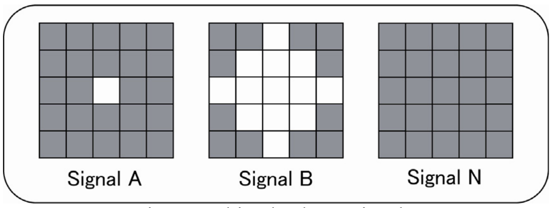

Fig. 7 Multi-valued area signals.

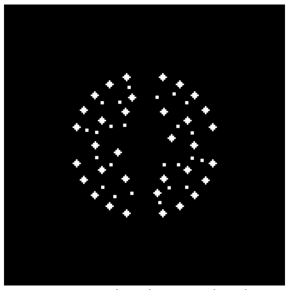
Fig. 8 An ID pattern by three-valued area signals.

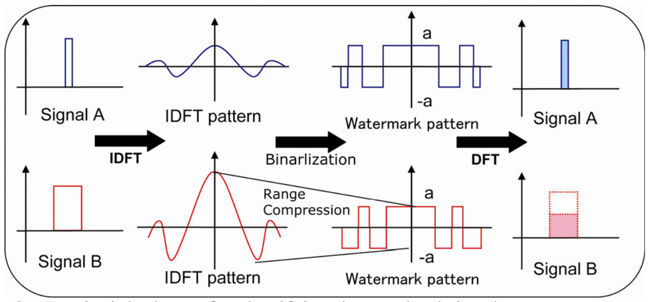

Fig. 9 Principle theory for classifying three-valued signals.

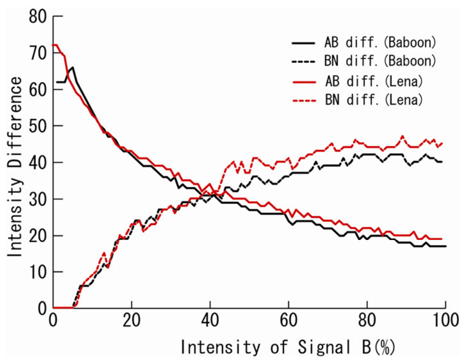

Fig. 10 Intensity of signal B v.s. intensity difference by using signals with multi-valued intensity and area.

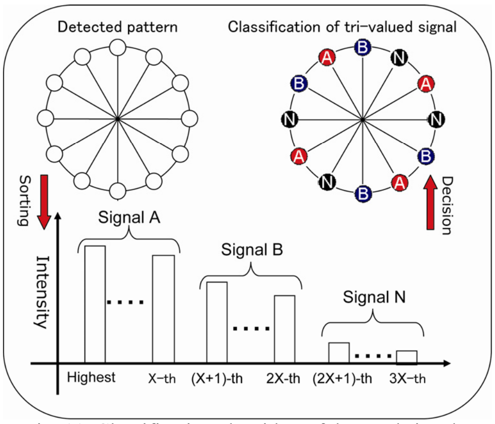

Fig. 11 Classification algorithm of detected signals.

(Fig. 12-a). Figure 12-b shows the constructed watermark by the IDFT and the binarization. Eight kinds of natural images in Fig. 13 were used for experiments.

Images with the embedded ID patterns were printed on professional photo papers with an inkjet printer Canon PIXUS MP500. We used the camera of a cellular phone Foma SH902i for taking those images with 960×1280 pixels by using the auto focus mode. Figures 14(a) and (b) show samples of captured images. The lighting environment is an indoor fluorescent lamp. We also used another signal pattern for experiments. In total, 16 images were used for the experiments.

Figures 14(c) and (d) show some results of the signal detection process. We used the maximum intensity within 9×9 pixels for each signal position (white squares in the figures). For all test images, signal detection succeeded. As shown in Fig. 14, the spectrum widely distributed on the ID pattern signals. For example, in Fig. 14(d), the roof with periodic texture appears as diagonal power in the restored DFT pattern. Though the eight kinds of images had various frequency responses, our algorithm could detect ID pattern correctly for all images.

V. Conclusions

This paper has proposed a digital watermarking technique for improving embedded information capacity stably and rapidly by using not only the strength of the multi-valued signal intensity but also multi-valued area together. Experiments were performed for various natural images, and the feasibility of the proposed method was confirmed.

References

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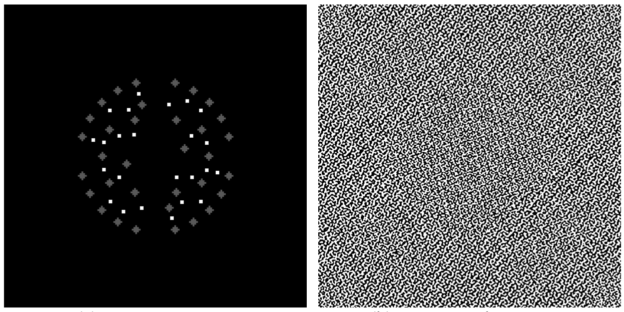


(a) ID pattern (b) Watermark pattern

Fig. 12. An ID pattern used in our experiment.

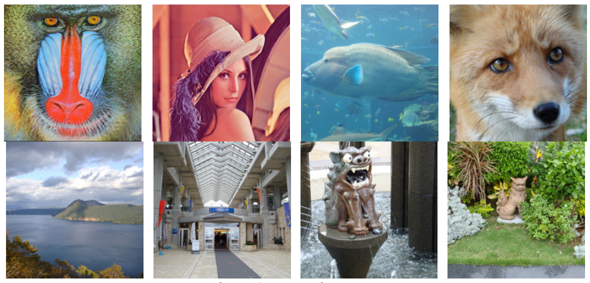
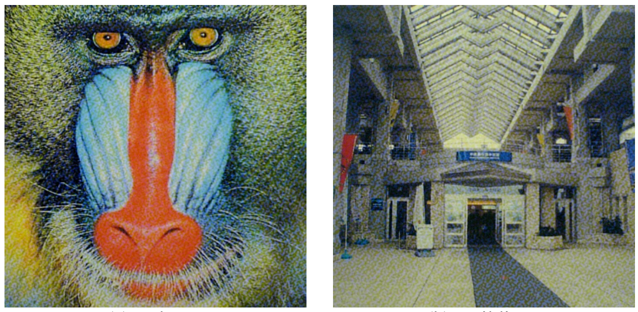
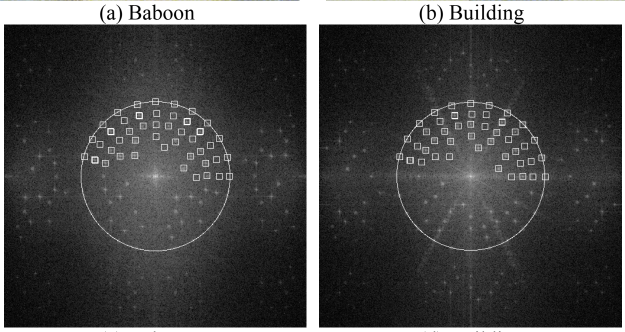


Fig. 13 Test images.



(a) Baboon (b) Building



(c) Baboon (d) Building

Fig. 14 (a),(b) Captured test images with embedded ID pattern. (c), (d) Detected signals.