International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:4, No:6, 2010

Binary Phase-Only Filter Watermarking with Quantized Embedding

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***Abstract*—**The binary phase-only filter digital watermarking embeds the phase information of the discrete Fourier transform of the image into the corresponding magnitudes for better image authentication. The paper proposed an approach of how to implement watermark embedding by quantizing the magnitude, with discussing how to regulate the quantization steps based on the frequencies of the magnitude coefficients of the embedded watermark, and how to embed the watermark at low frequency quantization. The theoretical analysis and simulation results show that algorithm flexibility, security, watermark imperceptibility and detection performance of the binary phase-only filter digital watermarking can be effectively improved with quantization based watermark embedding, and the robustness against JPEG compression will also be increased to some extent.

***Keywords*—**binary phase-only filter, discrete Fourier transform, digital watermarking, image authentication, quantization.

I. Introduction

THE digital watermarking of the Binary Phase-Only Filter (BPOF) proposed in [1]-[2] can facilitate better image authenticity and integrity authentication, by mean of embedding the phase information of the image with discrete Fourier transformation (DFT) into the corresponding magnitudes and utilizing the strong correlation between the image phase information and the image content.

As for the specific method for watermark embedding, the DFT to the original image is performed firstly. The magnitude of image after DFT transformation will be expressed in integer bit plane while the phase information can be transformed to BPOF with binarization, to replace the bit plane of a certain magnitude for watermark embedding. The image after watermark embedding can be obtained through inverse discrete Fourier transformation (IDFT).

In order to detect the watermark, the DFT will be applied to the covered image that needs to be tested for extracting the embedded information from the magnitudes, thus to calculate the correlation between the embedded information and the corresponding phase information to determine whether watermark is embedded in the image, and to authenticate the authenticity of the image as well.

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There are some other methods can be employed to replace the magnitude bit plane except for the BPOF, such as the watermark embedding through quantization [3]-[4]. In this paper, BPOF watermark is embedded through quantization magnitude by regulating the quantization steps on the frequencies of the magnitude coefficients of embedded watermark, that to be quantization embedded at the low frequency range. The results show that the algorithm flexibility and security can be improved with the watermark embedding through magnitude quantization, and the watermark imperceptibility and detection effectiveness can also be improved after regulating the quantization steps based on the frequency of the magnitude coefficients of the embedded watermark, while the robustness against JPEG compression can also be enhanced through quantifying embedded watermark at low frequency range.

II. Related Works

The procedures for embedding BPOF watermark by quantizing image DFT magnitude are listed as follows [1]-[3].

A. Watermark Imbedding

The amplitude and phase of the image by applying DFT are noted as $X(u,v)$ and $\varphi(u,v)$ respectively. The phase $\varphi(u,v)$ can be binarized to $B(u,v)$ with range $\{-1,+1\}$, and be encrypted and scrambled to $EB(u,v)$ to prevent watermarking counterfeiting.

The quantization step will be calculated subsequently with changeable quantization steps because the magnitude coefficients of image DFT are quite different. It's better to adopt the following formula to calculate the quantization steps of the magnitude coefficients rather than using the same quantization step:

$$\Delta(u,v) = \alpha \times 10^{\lfloor \lg(X(u,v)) \rfloor} \qquad (1)$$

where α is a real number ranges from 0 to 1, and $\lfloor . \rfloor$ indicates rounding down.

The following formula is employed to quantize each magnitude coefficient:

$$X_w(u,v) = \begin{cases} X_\Delta(u,v)\cdot\Delta(u,v) & \text{if } EB(u,v) = -1 \text{ and } \mathrm{mod}(X_\Delta(u,v),2) = 0 \\ X_\Delta(u,v)\cdot\Delta(u,v) + \Delta(u,v) & \text{if } EB(u,v) = -1 \text{ and } \mathrm{mod}(X_\Delta(u,v),2) = 1 \\ X_\Delta(u,v)\cdot\Delta(u,v) & \text{if } EB(u,v) = +1 \text{ and } \mathrm{mod}(X_\Delta(u,v),2) = 1 \\ X_\Delta(u,v)\cdot\Delta(u,v) + \Delta(u,v) & \text{if } EB(u,v) = +1 \text{ and } \mathrm{mod}(X_\Delta(u,v),2) = 0 \end{cases} \qquad (2)$$

where $X_\Delta(u,v)$ indicates $\lfloor X(u,v)/(u,v) \rfloor$.

After quantization, $X_w(u,v)$ takes the nearest value to $X(u,v)$ from $2k\Delta(u,v)$ or $(2k+1)\Delta(u,v)$, which correspond to $EB(u,v)=1$ or $EB(u,v)=-1$ respectively.

Finally, two-dimensional inverse discrete Fourier transformation is applied to embed watermark to the image.

B. Watermark Detection

When applied DFT transform to the image to be tested, the transformed amplitude and phase are generated, noted as $X_T(u,v)$ and $\Delta_T(u,v)$ respectively. The phase-only filter (POF) can be calculated with the following formula,

$$T_{POF}(u,v)=\exp[-j\varphi_T(u,v)] \quad (3)$$

Quantization step can be calculated by,

$$\Delta_T(u,v)=\alpha\times 10^{\lfloor \log(X_T(u,v))\rfloor} \quad (4)$$

Embedded watermark $EB(u,v)$ can be extracted from the amplitude by:

$$EB_T(u,v)=\begin{cases}-1 & if \ \mathrm{mod}(round(X_{T\Delta}(u,v)/\Delta_T(u,v)),2)=0\\ +1 & if \ \mathrm{mod}(round(X_{T\Delta}(u,v)/\Delta_T(u,v)),2)=1\end{cases} \quad (5)$$

where $X_{T\Delta}(u,v)$ denotes $\lfloor X_T(u,v)/\Delta_T(u,v)\rfloor$.

$B_T(u,v)$ will be decrypted from $EB_T(u,v)$. Calculate the correlation plane between $B_T(u,v)$ and $T_{POF}(u,v)$.

$$Corr=FT^{-1}(T_{POF}(u,v)*B_T(u,v)) \quad (6)$$

Finally, we determine whether $B_T(u,v)$ and T_{POF} are similar based on whether the peak value exists in the correlation plane and the relative value of the peak, so as to determine whether BPOF watermarks are embedded in the image. We assume that $P_{\max}$ and P_{mim} are the maximum value and the second maximum value on the correlation plane (exclude 7×7 neighborhood that corresponds to $P_{\max}$ when calculating P_{mim}), and μ is the mean value of the correlation plane. There are two criteria used to describe the correlation characteristics [5] as peak-to-average-correlation-energy $PACE=20\lg(P_{\max}/\mu)$ and peak-to-secondary-peak ratio $PSR=20\lg(P_{\max}/P_{\min})$. The former is used to judge the existence of watermark, and when its value is getting larger, more likely a watermark exists. The latter is used to determine the possibility of watermark false alarm, and when its value is getting larger, the possibility of false alarm is getting lower.

C. Testing Results

The above quantifying embedded watermark method is used for a 512×512 peppers image in [3], which obtains the following results.

Imperceptibility: when BPOF watermark is embedded by quantization magnitudes, the imperceptibility of the embedded watermark tends to decline, but there are ups and downs. The reason lies in the characteristics of quantization, when some larger quantization steps are used, the error caused by quantified amplitudes (especially important amplitudes) is smaller than that caused when some smaller quantization steps are used, thus the imperceptibility is better.

Detection efficiency: detection efficiency tends to increase with the quantization step.

Robustness against JPEG compression: embedded watermark has relatively weaker capacity against JPEG compression compared with the original algorithm of BPOF watermark embedding in amplitude bit plane proposed in [3].

In general, quantization step c has a wider range in quantization embedded watermark than that of magnitude bit-plane embedded watermark. In a 512×512 8-bit grayscale, the number of magnitude bit-planes is $\log_2(512\times512)+8=26$, and the quantization step can be any value between 0 and 1. The intensity of the embedded watermark is more easily controlled, more flexible, more difficult to be forged, speculated and destroyed, and safer than that of magnitude bit-planes embedded watermark. The main disadvantage of using embedded quantization is less robustness against JPEG compression.

III. Regulating the Quantization Steps Based on the Frequencies of the Magnitude Coefficients

A. Algorithm Principle

Apart from the absolute value of the magnitude coefficients, the frequency of each magnitude coefficient also needs to be considered for the calculation of quantization step. Due to the relatively higher influence of the low frequencies on image quality, the low frequencies magnitude coefficient will use the relatively smaller quantization step while the high frequencies magnitude coefficient will use the relatively larger one. Therefore, the quantization step will be determined not only by the absolute value of the magnitude coefficients but also the frequency of each magnitude coefficient.

Specific method are as follows: take α as the reference quantization step and introduce the quantization step adjustment factor StepFactor (the value of StepFactor can be calculated with the linear and nonlinear function between frequencies of the magnitude coefficients and the DFT transform origin), then take the product of reference quantization step α and quantization step adjustment factor StepFacor to as the final quantization step.

B. Experiment Results

In order to evaluate the influence to the algorithm performance when regulating the quantization steps based on the frequencies of the magnitude coefficients, experiments are carried out for a 512×512 peppers image. The results when regulating the quantization steps based on the frequencies of the magnitude coefficients have been listed out for performance comparison.

When the quantization steps are not regulated based on the frequencies of the magnitude coefficients, the watermark strength can only be determined by the quantization step α, but when the quantization steps are regulated based on the frequencies of the magnitude coefficients, the watermark em-

International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
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bedding strength of each magnitude coefficient can be determined by the product of α and StepFactor. Therefore, the performance should not only be compared when α is in the same value, but also be compared comprehensively with imperceptibility and detection efficiency.

TABLE I
IMPERCEPTIBILITY AND DETECTION EFFICIENCY WHEN THE QUANTIZATION STEPS ARE **NOT** REGULATED BASED ON THE FREQUENCIES OF THE MAGNITUDE COEFFICIENTS

quantization step α	SNR	PSNR	PACE	PSR
0.18	34.45	39.67	40.70	24.79
0.20	32.78	38.00	42.83	28.00
0.23	31.13	36.35	45.29	29.67
0.26	30.74	35.95	44.81	29.44
0.31	29.63	34.85	48.28	32.99

TABLE II
IMPERCEPTIBILITY AND DETECTION EFFICIENCY WHEN THE QUANTIZATION STEPS ARE REGULATED BASED ON THE FREQUENCIES OF THE MAGNITUDE COEFFICIENTS

Reference quantization step α	SNR	PSNR	PACE	PSR
0.40	43.17	48.38	47.32	31.05
0.50	36.44	41.66	49.15	33.42
0.60	38.93	44.14	50.19	34.39
0.70	37.78	42.99	50.71	35.19
0.80	35.84	41.05	50.84	34.51

In Table I and Table II, we can easily find when the quantization steps are regulated based on the frequencies of the magnitude coefficients, detection efficiency can be significantly increased in case that imperceptibility is same or even higher, for example, when the reference quantization step α in Table II is 0.50, the Imperceptibility and detection efficiency are higher than that in Table I.

In general, the imperceptibility and detection efficiency can be significantly improved when the quantization steps are regulated based on the frequencies of the magnitude coefficients, however, the improvement in Robustness against JPEG compression performance is not obvious.

To further improve the algorithm performance, some calculation methods that further improve the quantization step need to be considered, a better way to quantize embedded watermarks, such as HVS characteristics calculation method under DFT in [6], to improve the calculation of quantization step;

BPOF watermarks can also be embedded in the low-frequency domain of image DFT transformation to improve performance against JPEG compression as discussed in next section.

IV. EMBEDDING BPOF WATERMARKS IN THE LOW-FREQUENCY DOMAIN OF IMAGE DFT TRANSFORMATION

The imperceptibility and detection efficiency of the embedded watermarks can be significantly improved when the quantization steps are regulated based on the frequencies of the magnitude coefficients, however, the improvement in Robustness against JPEG compression performance is not obvious. If the watermarks are embedded in low frequency other than the whole frequency domain, Robustness against JPEG compression capacity can also be improved with imperceptibility and detection efficiency as JPEG compression has a relatively small influence on low frequency coefficients.

In order to study the performance of low-frequency domain embedded watermarking, experiments are carried out for a series of images in this paper. The experimental results are listed and analyzed in detail for 512×512 peppers images.

To ensure the symmetry when embedding BPOF watermarks, the watermarks are embedded in symmetric frequency range (except for the whole frequency domain) around the center after moving DFT transform origin to it except the whole frequency embedding. The experiment results for embedding watermarks in 512×512, 385×385, 257×257, 193×193, 129×129, 65×65, 33×33, 17×17, 9×9 and other frequency range are given in the following Fig. 1 and Fig. 2.

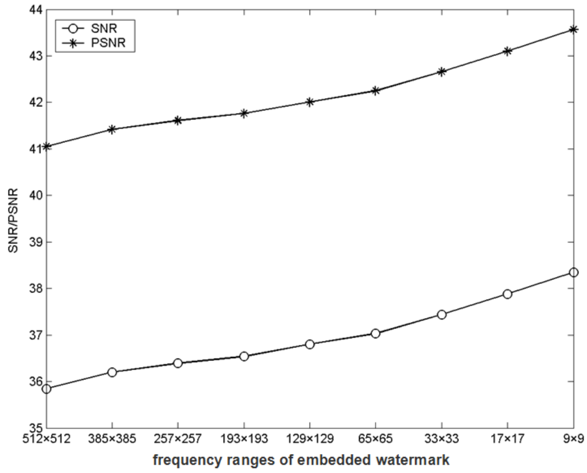


Fig. 1 Imperceptibility of the quantization embedded watermark in different frequency ranges (reference quantization step α =0.8)

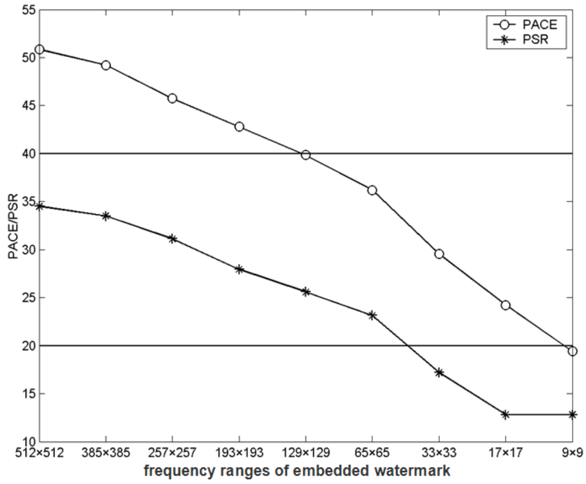
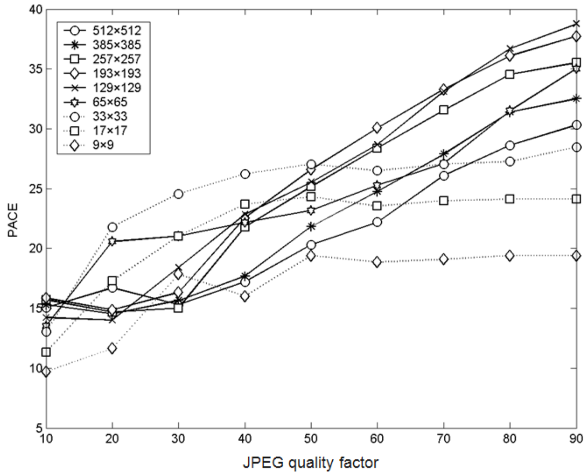


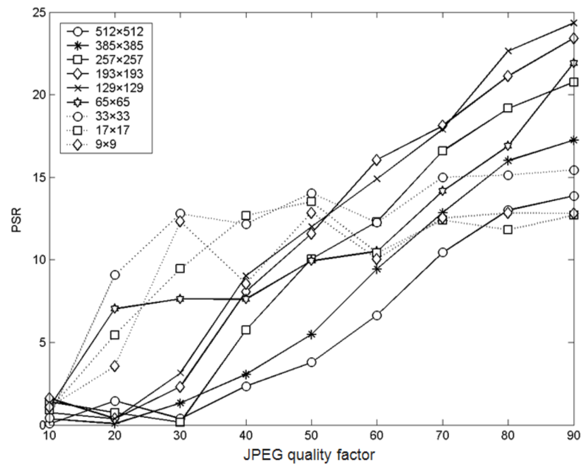
Fig. 2 Detection efficiency of the quantization embedded watermark in different frequency ranges (reference quantization step α =0.8)

The imperceptibility of the embedded watermark can be slightly improved when the frequency range decreases, but not obvious, because the watermark is always embedded in important amplitude coefficients, only non-important coefficients are affected, which has little influence on the imperceptibility.

Detection values PACE/PSR decreases when the frequency range of the watermark decreases, because PACE/PSR value is in relation to the *Corr* of the correlation plane, and the correlation plane is getting smaller when the frequency range of embedded watermark is getting smaller, which makes the PACE/PSR value decreases with it, that is, PACE/PSR value is in relation to the size of the embedded watermark area. In general, the existence of watermark can be correctly detected when PACE and PSR thresholds were taken as 40 and 20 [1, 2], therefore, when the frequency range of embedded watermark is not too small, the watermark can correctly detected. For example, when the frequency range of a 512×512 image is above 129×129, watermark can correctly detected (seen in Fig. 3).



(a)



(b)

Reference quantization step α =0.8 (a) PACE (b) PSR

Fig. 3 Robustness against JPEG compression performance of the quantization embedded watermark in different frequency ranges

The Robustness against JPEG compression capacity of the embedded watermark, first increases with the reduction of frequency range, then decreases when the frequency decreases to a certain degree.

In summary, when BPOF watermark is embedded in low frequency domain, the imperceptibility of the embedded watermark can be improved to a certain extent, and the JPEG compression resistance performance can also be improved while ensuring that the watermark can be correctly detected in case that the embedding scope of the watermark can meet certain conditions.

V. Conclusion

BPOF watermark embedding by quantizing amplitude coefficients is researched in this paper. The watermarking performances in conditions of quantization embedded watermark, regulating the quantization steps based on the frequencies of the magnitude coefficients and embedding BPOF watermarks in the low-frequency domain of image DFT transformation are analyzed in detail. The following conclusions can be drawn from the theoretical analysis and simulation results:

(1) As the selection scope is wider, and the number of quantization coefficients are more than that of magnitude bit-planes, the intensity of the embedded watermark are more easily controlled, more flexible and safer;

(2) The imperceptibility and detection efficiency of the embedded watermark are improved when regulating the quantization steps based on the frequencies of the magnitude coefficients;

(3) JPEG compression resistance performance of the embedded watermark embedding can be improved when embedding watermark in low-frequency domain;

(4) The overall security of the algorithm, the imperceptibility of the embedded watermark, detection efficiency of the embedded watermark and JPEG anti-compression performance can be achieved by integrating (1), (2), and (3).

Acknowledgment

This work is supported by the National High Tech Research and Development Plan of China under grant no. 2007AA-01Z445, and the Natural Science Foundation in Chongqing City of China under Grant No. CSTC2008BB2312.

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