Adaptive Quantization of Wavelet Packet Coefficients for Embedding and Extraction of Digital Watermarks

Chi-Man Pun and I-Kuan Kong

***Abstract*—**In this paper, a robust digital image watermarking approach of embedding and extraction of digital watermarks using adaptive quantization of wavelet packet coefficients was proposed. The original image is decomposed by discrete wavelet packet transform and the dominant wavelet coefficients are selected for watermark embedding from each sub-band except the lowest frequency one. Then, each watermark bit is adaptively embedded with different strength into the selected wavelet packet coefficients based on the odd or even value after quantization. Experimental results show that the proposed method is effective for copyright verification and robust to various common attacks such as Gaussian noise, JPEG compression, and without original image as references.

***Keywords*—**Watermarking, Wavelet packet, Adaptive Quantization, Copyright verification.

I. Introduction

DUE to the appearance of Internet and the explosive growth of digital technologies, a large number of applications in the areas of the multimedia communications and multimedia networking have been enable over the past decade. It is an essential concern for the authentication and the copyright protection from unauthorized manipulation of digital image, audio and video data. Therefore, digital watermarking techniques has been proposed to add some watermarks in the multimedia data that authenticates the legal copyright holder and that cannot be manipulated or removed without damage the multimedia data so that they are no commercial value any more [1]. Digital watermarking [2] has seen a large number of applications. Due to the impressive performance in transparency, robustness, sensitivity, and blind detection for the various applications, the wavelet-based watermarking schemes and image-adaptive watermarking schemes become great interested schemes. In 1997, Xia et al. [3] introduced a multiresolution watermarking method for digital images. Their method is based on discrete wavelet transform (DWT) and inserting pseudorandom codes to the large coefficients at high and middle-frequency bands of DWT of an image. Their method is robust to some common image compressions and halftoning but the detection of the watermark is dependent on the noise level in an image. Hsu et al. [4] proposed a multiresolution-based technique for embedding digital watermarks into images. Ju et al. [5] proposed a scheme of digital image watermarking based on the combination of discrete wavelet transform (DWT) and independent components analysis (ICA). Inoue et al. [6] introduced a watermarking scheme by grouping wavelet coefficients into insignificant or significant using zerotree and then embedding a watermark in the location of insignificant coefficients or in the location of the thresholded significant coefficients at the coarser scales. Hu et al. [7] proposed a watermarking scheme using pixel-based scaling. The scaling factors for the pixel-based method are adaptively determined by the effect of luminance and local spatial characteristics. Taskovski et al. [8] presented a low-resolution content-based watermarking scheme. During the embedding process, the watermark is embedded in the lowest resolution of three-level wavelet decomposition incorporated with a visual modeling of the local image characteristics. Wei et al. [1] introduced a perceptually based watermarking technique for image. The watermark is embedded in the wavelet coefficients and its amplitudes are controlled by the wavelet coefficients so that watermark noise does not exceed the just-noticeable difference of each wavelet coefficient. Barni et al. [9] proposed a watermarking algorithm, which is based on the masking of the watermark according to the characteristics of the human visual system (HVS). Kundur et al. [10] and Tu et al. [11] presented a fragile watermarking approach which embeds a watermark in the discrete wavelet domain of the image or audio by quantizing the corresponding coefficients. However, the performance of their approaches for JPEG compression is unknown and uses the less adaptive discrete wavelet transform (DWT).

In this paper, we introduce a robust digital image watermarking approach by adaptive quantization of wavelet packet coefficients. The original image is decomposed by discrete wavelet packet transform and the dominant wavelet coefficients are selected for watermark embedding from each sub-band except the lowest frequency one. Then, each watermark bit is adaptively embedded with different strength into the selected wavelet packet coefficients based on the odd

This work was supported in part by the Research Committee of University of Macau under the Grant: RG070/07-08S/PCM/FST.

C.-M. Pun and I.-K. Kong are with the Department of Computer and Information Science, University of Macau, Macau S.A.R., China. (e-mail: cmpun@ umac.mo). Manuscript received January 3, 2007, Revised Nov.4, 2007

or even value after quantization. The outline of this paper is organized as follows. In next section, we briefly introduce and review the standard 2-D discrete wavelet packets transform techniques. In section III, we present our proposed algorithms for embedding and extracting the watermark by adaptive quantization of wavelet packet coefficients. The experiment results for robustness of our proposed method to various attacks are presented in Section IV. Finally, conclusions are drawn in Section V.

II. Discrete Wavelet Packet Transform

The 2-D discrete wavelet packet transform (DWPT) is a generalization of 2D discrete wavelet transform (DWT) that offers a richer range of possibilities for image analysis. In 2D-DWT analysis, an image is split into an approximation and three detail images. The approximation image is then itself split into a second-level approximation and detail images, and the process is recursively repeated. So there are n+1 possible ways to decompose or encode the image for an n-level decomposition. In 2D-DWPT analysis, the three details images as well as the approximation image can also be split. So there are 4^n different ways to encode the image, which provide a better tool for image analysis. The standard 2D-DWPT can be described by a pair of quadrature mirror filters (QMF) ***H*** and ***G*** [12]. The filter ***H*** is a low-pass filter with a finite impulse response denoted by $h(n)$. And the high-pass ***G*** with a finite impulse response is defined by:

$$g(n) = (-1)^n h(1-n) \text{, for all } n$$

The low-pass filter is assumed to satisfy the following conditions for orthonormal representation:

$$\sum_n h(n)h(n+2j) = 0 \text{, for all } j \neq 0$$

$$\sum_n h(n)^2 = 1$$

$$\sum_n h(n)g(n+2j) = 0 \text{, for all } j$$

The 2D discrete wavelet packet decomposition of an $M \times N$ discrete image x up to level p+1 ($0 \le p \le \min(\log_2(N), \log_2(M))$) is recursively defined in terms of the coefficients of level p as follows:

$$C^{p+1}_{4k,(i,j)} = \sum_m \sum_n h(m)h(n)C^p_{k,(m+2i,n+2j)}$$

$$C^{p+1}_{4k+1,(i,j)} = \sum_m \sum_n h(m)g(n)C^p_{k,(m+2i,n+2j)}$$

$$C^{p+1}_{4k+2,(i,j)} = \sum_m \sum_n g(m)h(n)C^p_{k,(m+2i,n+2j)}$$

$$C^{p+1}_{4k+3,(i,j)} = \sum_m \sum_n g(m)g(n)C^p_{k,(m+2i,n+2j)}$$

where $C^0_{0,(i,j)} = x_{(i,j)}$ is given by the intensity levels of the image x.

Since the image x has only a finite number of pixels, different methods such as symmetric, periodic or zero padding should be used for the boundary handling. At each step, we decompose the image C^p_k into four quarter-size images C^{p+1}_{4k}, C^{p+1}_{4k+1}, C^{p+1}_{4k+2} and C^{p+1}_{4k+3}.

The inverse wavelet packet transform of a discrete image x from wavelet coefficients at level $p+1$ can be achieved by applying recursively the following formulae until $C^0_{0,(i,j)}$ is obtained:

$$C^p_{k,(i,j)} = \sum_m \sum_n h(m)h(n)C^{p+1}_{4k,(m+2i,n+2j)} + \sum_m \sum_n h(m)g(n)C^{p+1}_{4k+1,(m+2i,n+2j)} + \sum_m \sum_n g(m)h(n)C^{p+1}_{4k+2,(m+2i,n+2j)} + \sum_m \sum_n g(m)g(n)C^{p+1}_{4k+3,(m+2i,n+2j)}$$

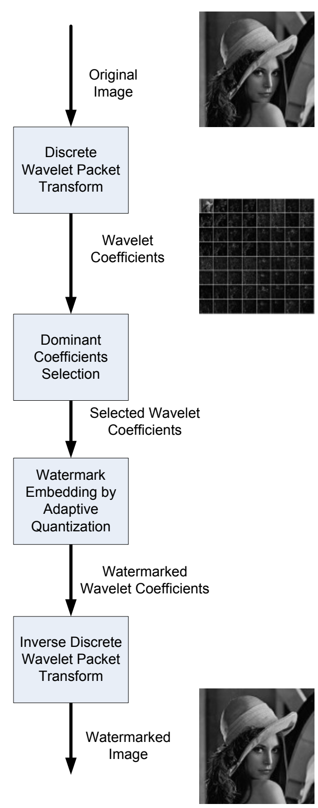


Figure 1. Watermark Embedding by Adaptive Quantization of Wavelet Packet Coefficients

III. Watermark Embedding and Extraction by Adaptive Quantization

Fig. 1 illustrates the basic idea of adaptive watermark embedding by quantization of wavelet packet coefficients. The proposed method is a four-step process. First, the original image is decomposed by discrete wavelet packet transform up to p-level. Second, the dominant wavelet coefficients are selected for watermark embedding from each sub-band except the lowest frequency one. This can ensure that the embedded watermark will not affect the visual quality of the original too much, as well as be robust to various attacks. Third, each watermark bit is adaptively embedded with different strength into the selected wavelet packet coefficients based on the odd or even value after quantization. Finally, the inverse discrete wavelet packet transform is applied to the watermark embedded coefficients to obtain the watermarked image. The details of the proposed method for adaptive watermark embedding are as follows.

Algorithm I: Watermark Embedding by Adaptive Quantization

Step 1. For a given $N \times N$ image, apply the standard *discrete wavelet packet transform* (as describe in section II) up to p-level, which produce a total of m sub-bands of wavelet coefficients $C^p_{k,(i,j)}$, where $p \le \log_2(N)$, $k = 1,\cdots,4^p - 1$ and i, j $= 0,1,\ldots,2^{\log N - p} - 1$.

Step 2. The M most dominant wavelet coefficients $D^p_{k,m}$ are selected from each sub-band $C^p_{k,(i,j)}$ except the lowest frequency one by sorting the coefficients of the sub-band, where $k = 1,\cdots,4^p - 1$ and $m = 1,\cdots,M$.

Step 3. Each selected wavelet coefficient $D^p_{k,m}$ is then decided to be ODD or EVEN by dividing it with a quantization parameter Δ.

$$Q(D^p_{k,m}) = \begin{cases} 1, & if \quad \left\lfloor \left| \dfrac{D^p_{k,m}}{\Delta} \right| \right\rfloor = ODD, \quad (1,3,5\cdots) \\ 0, & if \quad \left\lfloor \left| \dfrac{D^p_{k,m}}{\Delta} \right| \right\rfloor = EVEN, \quad (2,4,6\cdots) \end{cases}$$

Step 4. Adaptively embedding the digital watermark W of $M*(4^p - 1)$ bits with different strength into the selected wavelet coefficients $D^p_{k,m}$ by

$$D^p_{k,m} = \begin{cases} D^p_{k,m}, & if\ W_i = Q(D^p_{k,m}) \\ D^p_{k,m} + (2\left\lfloor \log\left|D^p_{k,m}\right| \right\rfloor + 1) * \Delta, & if\ W_i \ne Q(D^p_{k,m}) \end{cases}$$

where $k = 1,\cdots,4^p - 1$, $m = 1,\cdots,M$ and $i = 1,\ldots,M*(4^p - 1)$

Step 5. Apply the *inverse discrete wavelet packet transform* to the modified wavelet coefficients to obtain the watermarked image.

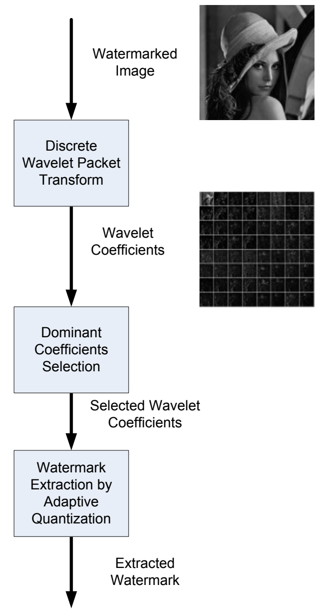


Figure 2. Watermark Extraction by Adaptive Quantization of Wavelet Packet Coefficients

Fig. 2 illustrates the basic idea of adaptive watermark extraction by quantization of wavelet packet coefficients. The watermarked image is decomposed by discrete wavelet packet transform up to p-level. Similar to the process of watermark embedding, the dominant wavelet coefficients are selected for watermark extraction from each sub-band except the lowest frequency one. Finally, the digital watermark can be extracted by the quantization of the selected domain wavelet packet coefficients. The details of the proposed method for the watermark extraction are as follows.

Algorithm II: Watermark Extraction by Quantization

Step 1. For a given $N \times N$ watermarked image, apply the standard *discrete wavelet packet transform* (as describe in section II) up to p-level, which produce a total of m sub-bands of wavelet coefficients $C^p_{k,(i,j)}$, where $p \le \log_2(N)$, $k = 1,\cdots,4^p - 1$ and i, j $= 0,1,\ldots,2^{\log N - p} - 1$.

Step 2. The M most dominant wavelet coefficients $D^p_{k,m}$ are selected from each sub-band $C^p_{k,(i,j)}$ except the lowest frequency one by sorting the coefficients of the sub-band, where $k = 1, \cdots, 4^p - 1$ and $m = 1, \cdots, M$.

Step 3. The digital watermark W is then extracted from the selected wavelet coefficients $D^p_{k,m}$ by

$$W_i = \begin{cases} 1, & if \quad \left\lfloor \left| \dfrac{D^p_{k,m}}{\Delta} \right| \right\rfloor = ODD, \quad (1, 3, 5 \cdots) \\ 0, & if \quad \left\lfloor \left| \dfrac{D^p_{k,m}}{\Delta} \right| \right\rfloor = EVEN, \quad (2, 4, 6 \cdots) \end{cases}$$

where $k = 1, \cdots, 4^p - 1$, $m = 1, \cdots, M$ and $i = 1, \ldots, M * (4^p - 1)$

.

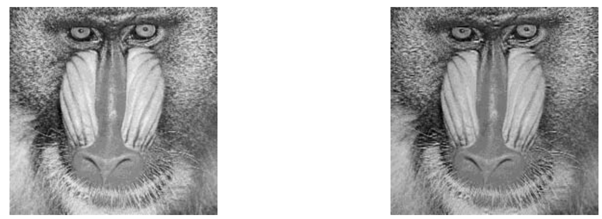
IV. Experimental Results

In the experiments, the proposed watermarking embedding and extraction methods are evaluated with the commonly used images: Lena, Plane, and Mandri, available from the USC-SIPI image database[1]. For the wavelet packet transform as describe in the Algorithm I, a three levels and full wavelet packet transform is used. In uniqueness test of watermark extraction, 1000 extra watermarks are embedded into the image and then compare with the real extracted watermark. The experiment results that no one matches the original watermark except the real extracted watermark. Thus, the uniqueness is guaranteed. For testing of visual quality of watermarked images without any attack, three different watermarked images are participated in the experiment. The extraction percentage is equal to 100%. Figure 4 shows the visual quality of watermarked images. Figure 5 shows the different values of psnr of each watermarked image during the value of Δ is increasing.

In order to measure the robustness of the watermark, we attempt to attack the watermarked image by JPEG compression and adding Gaussian noise. Figure 6 shows the original images and the watermarked images during the quality of JPEG compression are equal 60. In Table 1, we can see that no matter the quality of compression is, the value of Δ remains unchanged. When the quality of compression is higher, the value of db is higher as well. The compression size of image is larger at this moment. When the quality of compression is lower, the value of db is lower. The compression size of image is much smaller at this moment. We found that the value of Δ is very small during the quality of compression is lower. It means that the proposed method is a great and robust method against JPEG compression.

(a) Δ =3, db = 43.9 (b) Δ =30, db = 25.3

(c) Δ =3, db = 44 (d) Δ =30, db = 25.9



(e) Δ =3, db = 42.5 (f) Δ =30, db = 24.9

Figure 4. The visual quality of watermarked images.

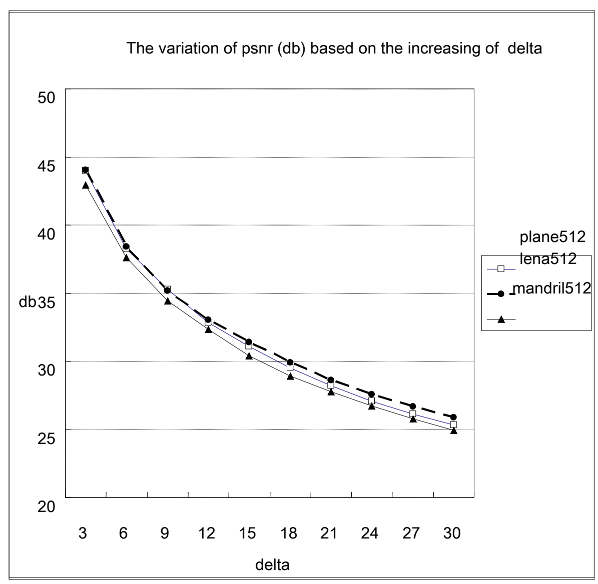


Figure 5. The variation of psnr (db) based on the increasing of Δ .

At Figure 7, it shows different values of Δ and db when extraction percentage is equal to 100% during the Gaussian noise is adding to a watermarked image. In order to guarantee the robustness of watermark, the

[1] http://sipi.usc.edu/database/

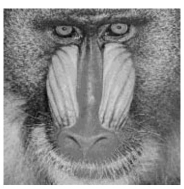
larger value of Δ is needed. It means that when the variance of Gaussian noise is bigger, the value of Δ is larger. You can see Figure 7(c). The value of Δ is larger than the left and middle columns.

(a) The original image

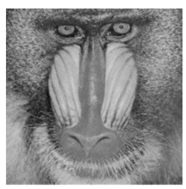
(b) Δ = 25, db = 36.9

(c) The original image

(d) Δ = 25, db = 36.3



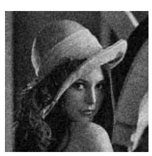
(e) The original image



(f) Δ = 35, db = 34.3

Figure 6. The visual quality of watermarked images with quality of JPEG compression = 60 when extraction percentage =100%.

(a) Δ = 16
db = 20.2



(b) Δ = 35
db = 15.8

(c) Δ = 43
db = 11.5

Figure 7. (a) – (c) show the different values of Δ and db when extraction percentage = 100% during adding Gaussian noise with variance 0.01(left), 0.03(middle) and 0.1(right) .

Table 1. The variations of delta, db and compression size when extraction percentage = 100% during the JPEG compression is applied.

Image / Quality	plane512	lena512	Mandril 512
Qual. = 90 Δ / *db*	3/41.9	4/40.8	5/41.2
File size (com./org.)	56KB/ 258KB	58KB/ 258KB	83KB/ 258KB
Qual. = 80 Δ / *db*	3/ 39.3	4/38.6	5/37.5
File size (com./org.)	37KB/ 258KB	37KB/ 258KB	60KB/ 258KB
Qual. = 70 Δ / *db*	3/ 37.9	4/37.2	5/35.6
File size (com./org.)	30KB/ 258KB	28KB/ 258KB	50KB/ 258KB
Qual. = 60 Δ / *db*	3/ 36.9	4/36.2	5/34.3
File size (com./org.)	25KB/ 258KB	23KB/ 258KB	43KB/ 258KB

Copyright is a set of exclusive rights that regulate the use of a particular expression of an idea or information. We have applied various attacks to check the robustness of watermark in section 3. The truth tells us that the robustness of watermark is guaranteed. The extraction percentage is equal to 100% where JPEG compression and Gaussian noise attacked on watermarked images. The visual qualities of watermarked images are degraded but the extracted watermark still remains unchanged. It means that the percentage of copyright verification is equal to 100%.

V. Conclusion

A robust digital image watermarking approach using adaptive quantization of wavelet packet coefficients was proposed in this paper. The dominant wavelet coefficients are selected for watermark embedding from each sub-band except the lowest frequency one. The watermark bit is adaptively embedded with different strength into the selected wavelet packet coefficients based on the odd or even value after quantization. Experimental results show that the proposed method is effective for copyright verification and robust to various common attacks such as Gaussian noise, JPEG compression, and without original image as references. However, the proposed method relied on the adjustment of quantization parameters for different images and attacks. Future work may focus on the prediction of quantization parameter from visual quality of images.

References

[1] G. L. Friedman, "The trustworthy digital camera: restoring credibility to the photographic image," *IEEE Trans. Consumer Electron.,* vol. 39, pp. 905-910, 1993.

[2] X. Xia, C. G. Boncelet, and G. R. Arce, "A multiresolution watermark for digital images," in *Proc. Int. Conf. Image Processing*, Santa Barbara, CA 1997, pp. 548 - 551.

[3] H. Inoue, A. Miyazaki, A. Yamamoto, and T. Katsura, "A digital watermark based on the wavelet transform and its robustness on image compression," in *IEEE ICIP*, 1998, pp. 391-395.

[4] M.-J. Tsai, K.-Y. Yu, and Y.-Z. Chen, "Wavelet packet and adaptive spatial transformation of watermark for digital images authentication," in *IEEE ICIP*, 2000, pp. 450-453.

[5] J. L. Vehel and A. Manoury, "Wavelet packet based digital watermarking," in *Proc. 15th Int. Conf. Pattern Recognit.*, Barcelona 2000, pp. 413 - 416.

[6] Y. Hu and S. Kwong, "Wavelet domain adaptive visible watermarking," *Electron. Lett.,* vol. 37, pp. 1219 - 1220, 2001.

[7] D. Taskovski, S. Bogdanova, and M. Bogdanov, "A low resolution content based watermarking of images in wavelet domain," in *Proc. 2nd Int. Symp. Image and Signal Process. Analysis*, Pula 2001, pp. 604 - 608.

[8] Z. H. Wei, P. Qin, and Y. Q. Fu, "Perceptual digital watermark of images using wavelet transform," *IEEE Trans. Consumer Electron.,* vol. 44, pp. 1267 - 1272, 1998.

[9] M. Barni, F. Bartolini, and A. Piva, "Improved wavelet-based watermarking through pixel-wise masking," *IEEE Trans. Image Processing,* vol. 10, pp. 783 - 791, 2001.

[10] B. Chen and G. W. Wornell, "Achievable performance of digital watermarking systems," in *IEEE Int. Conf. Multimedia Computing and Systems*, Florence 1999, pp. 13 - 18.

[11] B. Chen and G. W. Wornell, "Quantization index modulation: a class of provably good methods for digital watermarking and information embedding," *IEEE Trans. Inform. Theory,* vol. 47, pp. 1423 - 1443, 2001.

[12] S. Mallat, "A theory for multiresolution signal decomposition: The wavelet decomposition," *IEEE Trans. PAMI,* vol. 11, pp. 674-693, 1989.

Chi-Man Pun received the B.Sc. and M.Sc. degrees from the University of Macau in 1995 and 1998 respectively, and Ph.D. degree in Computer Science and Engineering from the Chinese University of Hong Kong in 2002. He currently is an assistant professor at the Department of Computer and Information Science of the University of Macau. His research interests include Content-Based Image Indexing and Retrieval, Digital Watermarking, Pattern Recognition, and Computer Vision.