AN INVERTIBLE QUANTIZATION BASED WATERMARKING APPROACH

Mohammad J. Saberian, Mohammad A. Akhaee, and Farokh Marvasti

Advanced Communications Research Institute (ACRI),
Department of Electrical Engineering, Sharif University of Technology, Tehran, Iran
Saberian@ee.sharif.edu, akhaee@ee.sharif.edu, and marvasti@sharif.edu
http://acri.sharif.edu

ABSTRACT

In this paper a new class of invertible watermarking approach based on quantization has been introduced. Based on the necessary conditions (blindness, reversibility and imperceptibility), a set of linear convex functions which satisfy these requirements are found. Then the optimum of this function set with the least distortion has been selected. The main advantage of this method is that the inserted distortion can be easily controlled by adjusting quantization levels. The low computational complexity is another advantage of this method. Experimental results show that the proposed algorithm achieves higher embedding capacity while its distortion is lower than other invertible watermarking techniques.

***Index Terms*—**High data rate, Quantization, Reversible watermarking

1. INTRODUCTION

Watermarking is referred as a process of embedding some specific data imperceptibly into a cover media called host signal. In fact, data embedding is achieved by imposing a quite small distortion to the host signal for various applications such as secret communication, copyright protection, fingerprinting, etc [1]. In some practical issues, any distortion caused by watermarking is intolerable. In these cases, it is necessary to recover the original signal after data extracting without any loss. For instance, in medical diagnosis and law enforcement, it is vital to reconstruct the original signal when the embedding message is retrieved. Also, in expense of high cost, high resolution aerial images are obtained for some other post processing. Thus, any distortion that reduces this precision should be removed completely. The watermarking algorithms satisfying above qualifications are called reversible, lossless or distortion-free [5]-[13].

Although, several watermarking algorithms have been already developed, they rarely are reversible. For example, the Least Significant Bit plane (LSB) scheme proposed in [2] is not invertible due to bit substitution by data. Another well-known watermarking approach called Spread Spectrum (SS) [3] is lossy because of truncation and round-off error. Furthermore, the Quantization Index Modulation (QIM) which is the base of several watermarking techniques [4] is not distortion-free owing to the error of quantization.

Several reversible watermarking algorithms have been proposed recently. In [5], using modulo 256 addition, a reversible watermarking algorithm for the eight-bit gray scale image is presented. Macq *et al*. [6] employed a lossless multi resolution transform domain to develop a robust reversible marking approach considering the patchwork algorithm [7] and modulo 256 addition. Based on integer wavelet transform, a distortion-free watermarking technique is presented in [8]. Celik *et al*. developed a generalized reversible version of LSB technique by developing a prediction based conditional entropy coder [9]. Moreover, applying the Difference Explanation (DE), Tian [10] embedded data into the high and middle frequency components of an image using integer wavelet transform. Expanding this approach [11] used the (DE) in triplet. Thereafter, Ni *et al.* watermarked data reversibly into the minimum point of image histogram [12]. In addition, an invertible watermarking scheme based on integer to integer wavelet transform has been proposed in [13].

In this paper, after investigating the requirements of invertible data hiding techniques, an optimum quantization based watermarking solution has been proposed. The distortion of the proposed algorithm is analytically investigated and its parameters are selected to minimize the distortion. Moreover, for a Gaussian host signal, the capacity of the algorithm has been determined. Finally, in order to achieve better performance, a new transformation domain is introduced.

The rest of the paper is organized as follows. Section 2 is taking into account the requirements of a reversible watermarking technique. Then an optimum solution is presented in section 3. Section 4 is devoted to distortion and capacity calculation. Experimental results are demonstrated in section 5, and finally section 6 concludes the paper.

2. REVESIBLE WATERMARKING REQUAIMENTS

In this section the problem of how watermarking techniques based on quantization can be blind and reversible are investigated.

A typical watermarking method can be expressed in the following manner:

Assume $S=(s_1,s_2,....,s_n)$, $s_i \in X$ and $Q=\{q_1,q_2,.....,q_m\}$ to be the input signal and its quantization levels, respectively. Also $m=0, 1$ is the message bit.

Define functions $L_m(s): X \to Q$ which map a specific quantization level to sample s and $m=0,1$. One conventional example of $L(s)$ assigns the nearest quantization level to the input sample.Also consider functions $f_m(s,q): X \times Q \to X$. These functions are applied to the input signal during watermarking procedure.

In a quantization based watermarking process, for some specific samples s_i , the watermarked sample s_i' is achieved in the following manner:

$$P_m(s_i) = s_i' = f_m(s_i, L_m(s_i)) \qquad (1)$$

where P_m represents the process of embedding bit m.

Since the process should be invertible and blind, we look for functions f_m and L_m to satisfy the following requirements:

- In the absence of the original signal, the algorithm should be able to recognize whether the processes P_0 or P_1 is applied to the host signal S. In fact, the main idea is to design monotone processes (P_0 and P_1) in such a way that their corresponding ranges have different loci with no intersection. Therefore, at the receiver, based on the number of point in each locus, the embedded message is determined.
- After data extraction, the algorithm should be able to recover the original signal S from S' and extract the bit (m) using equation (1). This extraction is possible, if the functions f_m and L_m are defined properly to result $L_m(s_i)$ from S' and m.
- Besides, the distortion imposed to the host signal should be controllable to have an acceptable value.

Any set of functions that satisfies these requirements is a solution to this problem. These functions can define a reversible watermarking technique.

3. PROPOSED SOLUTION

Here, we present a suitable set of functions (f, L) to handle this problem as shown below:

$L_0(s)$ = The least quantization level greater than s.

$L_1(s)$ = The biggest quantization level smaller than s.

$$f_m(s_i, L_m(s_i)) = \frac{s_i + dL_m(s_i)}{d+1} \quad m = 0,1 \qquad (2)$$

where d is a designing parameter. This approach is called Weighted Quantization Method (WQM).

Since f_0 and f_1 are convex functions, it can be easily deduced that:

$$L_0(s) \le f_0(s, L_0(s)) \le \frac{L_1(s) + dL_0(s)}{d+1}$$

$$\frac{L_0(s) + dL_1(s)}{d+1} \le f_1(s, L_1(s)) \le L_1(s)$$

Thus, the range of the process P_0 is $\left[L_0(s), \frac{L_1(s)+dL_0(s)}{d+1}\right]$ and the range of P_1 is $\left[\frac{L_0(s)+dL_1(s)}{d+1}, L_1(s)\right]$. As discussed earlier, the watermarking algorithm is blind if these intervals have no intersection. Consequently, we have:

$$\frac{L_1(s) + dL_0(s)}{d+1} \le \frac{L_0(s) + dL_1(s)}{d+1} \qquad \Rightarrow d \ge 1$$

Therefore, the algorithm is blind if $d \ge 1$ and afterward, the embedded bit can be extracted. After extracting the message bit, the original signal should be recovered. As mentioned before, we should retrieve $L_m(s_i)$ from the watermarked signal (S'). According to definitions of f_m and L_m we have:

$$L_m(s_i') = L_m(f_m(x, L_m(s_i))) = L_m(s_i) \qquad (3)$$

Hence, using (2) and (3), the original signal is recoverable and a reversible watermarking approach can be achieved.

4. DISTORTION ANLYSIS

Assume the message bit should be inserted in an N length frame of the input signal. In this section, we suppose the host samples are independent and identically distributed (*iid*) with distribution function $f_s(s)$. The distortion power can be written as follows:

$$E\{|s' - s|^2\} = \frac{1}{4} E\{| f_1(s, L_1(s)) + f_0(s, L_0(s)) - 2s|^2\} \qquad (4)$$

$$\begin{aligned} DNR &= \frac{Md}{4(d+1)} E\{|L_0(s) + L_1(s) - 2s|^2\} \\ &= \frac{Md}{4(d+1)} \sum_i \int_{q_i}^{q_{i+1}} (q_i + q_{i+1} - 2x)^2 f_s(s) ds \end{aligned} \qquad (5)$$

where M is the number of frame samples participated in the watermarking process and q_i's are the quantization levels. Considering $f_s(s)$ to be Gaussian, $N(0,\sigma)$, the distortion can be estimated as follows:

$$DNR = \frac{Md}{(d+1)} \sum_i \left(\frac{4\sigma}{\sqrt{2\pi}} \left(q_i e^{-\frac{q_{i+1}^2}{2\sigma^2}} - q_{i+1} e^{-\frac{q_i^2}{2\sigma^2}} \right) + \left(4\sigma^2 + (q_i + q_{i+1})^2\right) \left(Q\left(\frac{q_{i+1}}{\sigma}\right) - Q\left(\frac{q_i}{\sigma}\right) \right) \right)$$

Hence, using the capacity relation proposed in [4]:

$$C = \frac{1}{2} \log_2(1 + DNR) \qquad (6)$$

According to (5), by adjusting M, d, and q_i the distortion can be easily controlled; decreasing the d parameter, we get less distortion. Therefore, since $d \geq 1$ and (4) is an ascending function of d, the imposed distortion is minimized when $d=1$. On the other hand, from geometrical point of view, it is apparent that increasing d, makes loci tighter and yields more robustness in the watermarking algorithm. Fig. 1. depicts these loci as a function of d.

Moreover, in order to reduce the amount of distortion, watermarking process can be applied to fewer number of samples in each frame. However, reducing the watermarked samples leads to harder decision making at the receiver. Another approach for distortion eliminating is to increase the number of quantization levels. Although, this idea imposes less distortion, the robustness will be diminished. It is worthwhile to note that the distance between the quantization levels are limited to the precision of the instrument.

The proposed technique not only can be used in the spatial domain, but also it can be applied in the other transform domain. In fact, watermarking in the transform domain can spread the imposed distortion to several primary domain samples leading to more transparency of the watermarked data. Another advantage of using transform domain is changing the distribution of the host signal samples. As an example, we apply the suggested technique to a simple transformation called Point to Point Graph (PPG). In this transform domain, the time samples of the host signal in each frame are put together in pairs in such a way that they make the set $\{(s_1, s_{1+k}), \ldots, (s_{2n-k}, s_{2n})\}$ where k is an arbitrarily number, called index of *PPG*. This process is performed on the $2k$ first samples and after that, it is repeated on the other samples.

If the input signal S is passed through the PPG transformation, using polar coordinate system we have:

$$PPG_k\{s_1, s_2, \ldots, s_{2n}\} = \{(s_1, s_{1+k}), \ldots, (s_{2n-k}, s_{2n})\} = \{(R_1, \theta_1), \ldots, (R_n, \theta_n)\}$$

The proposed method can be applied to signal $R = (R_1, R_2, \ldots, R_n)$ or $\theta = (\theta_1, \theta_2, \ldots, \theta_n)$ independently which we call them WQM-R and WQM-θ, respectively.

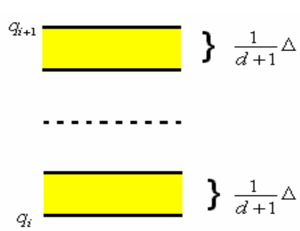

Fig. 1. The loci of the watermarked samples as a function of d

5. SIMULATION RESULTS

The proposed algorithm can be applied to any kind of media such as audio, image, or video. Here, as an example, the methods are simulated on a zero mean Gaussian signal, S, with the variance one. In order to achieve the least distortion, the parameter d is fixed at one. The simulation is performed in three ways: WQM, WQM-R and WQM-θ. The index of PPG transformation, k, is set to four in all frames.

The imposed distortion is depicted in Table. 1 for different payloads and number of quantization levels for WQM. As demonstrated in this table, the distortion is payload independent which is also confirmed by (5). The correlation parameter β can be written as:

$$\beta(x,y) = \frac{\left(\sum_i (x_i - \bar{x})(y_i - \bar{y})\right)}{\sqrt{\left(\sum_i (x_i - \bar{x})^2\right)\left(\sum_i (y_i - \bar{y})^2\right)}}$$

where $\bar{x}$, $\bar{y}$ are the mean of x, y, respectively.

In order to show the effect of the transformation on robustness, the BER of the proposed techniques against AWGN attack, are depicted in Fig. 2. In this figure, to have the same distortion (β=0.9821) the number of quantization levels for WQM, WQM-R and WQM-θ are set to 36, 16 and 10, respectively. In addition, the payload is fixed at 0.25 bps.

Table. 1.Distortion for various payloads and N_Q(number of quantization level)

Payload (bps)	N_Q =30		N_Q =40	
	SNR (dB)	β	SNR (dB)	β
0.01	28.14	0.9619	51.42	0.9827
0.1	28.40	0.9618	51.11	0.9828
0.2	28.41	0.9606	51.20	0.9829
0.5	28.17	0.9614	51.32	0.9827
1	28.39	0.9617	51.39	0.9828

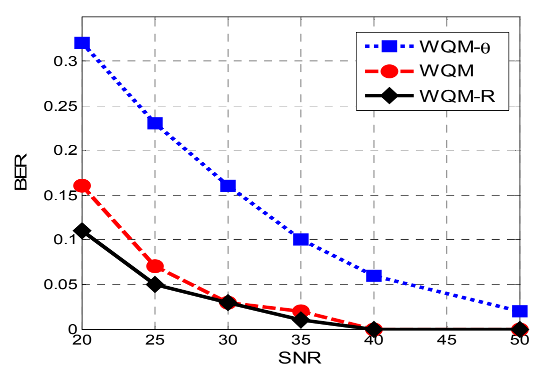

Fig. 2. BER of the proposed methods for 0.25 bps

As shown in Fig. 2, although the same distortion is imposed in the three proposed techniques, the WQM-R has the best performance.

Furthermore, in order to compare the proposed algorithm to other reversible watermarking approaches, we implement our scheme on conventional images such as Lena and Baboon. Fig. 3. depicts the original and watermarked image using proposed approaches.

As we can see the watermark signal is completely transparent. In addition, Table 2. presents a comparison between other reversible marking method and our proposed techniques on two typically different images: Lena and Baboon. This table illustrates that the WQM-R approach in both pictures has the best performance. It should be noted that the number of quantization in WQM, WQM-R and WQM-θ are set to 25, 45 and 55, respectively. It should be noted that the number of quantization levels are limited to the number of bits that each pixel is stored (8 bit plane for MATLAB images).

Table. 2. Comparison of different reversible methods in pure Payload (bps) and PSNR (dB)

Methods	Lena (512×512)		Baboon(512×512)	
	Payload	PSNR	Payload	PSNR
Xuan [8]	0.32	36.6	0.05	32.8
Cleik [9]	0.29	38	0.05	38
Tian [10]	0.38	40	0.45	33
Alattar [11]	0.41	38	0.42	37.5
Ni [12]	0.03	48.2	0.02	48.2
Lee [13]	0.5	41	0.5	38
WQM	0.5	41.1	0.5	40
WQM-R	**0.5**	**43.2**	**0.5**	**41.6**
WQM-θ	0.5	35.2	0.5	34.8

(a) (b) (c) (d)

Fig.3. a) The original image , watermarked image b) WQM, c) WQM-R, and d) WQM-θ

6. CONCLUSION

In this paper, the main characteristics of an invertible watermarking scheme are investigated and an optimum solution has been presented. The distortion of this technique, unlike the other approaches, is payload independent. In comparison with other reversible techniques, we can achieve a payload of 0.5 bps and keep the PSNR of the marked image above 40 dB. Moreover, we show that by applying the proposed algorithm to the introduced transform domain (PPG), higher capacity and less distortion is achieved.

For future work, we are looking for a general solution that satisfies the robustness as well as reversibility. Furthermore, we are going to obtain a theoretical bound for the proposed technique on the minimum distance between the quantization levels.

REFERENCES

[1] I. J. Cox, M. L. Miller, and J. A. Bloom, *Digital Watermarking*, San Mateo, CA: Morgan Kaufmann, 2002.

[2] J. Irvine and D. Harle, *Data Communications and Networks*: *An Engineering Approach*. New York: Wiley, 2002.

[3] J. Cox, J. Kilian, T. Leighton, and T. Shamoon, “Secure spread spectrum watermarking for multimedia,” *IEEE Trans. Image Process*., vol. 6, no.12, pp. 1673–1687, Dec. 1997

[4] B. Chen and G. W. Wornell, “Quantization index modulation: a class of provably good methods for digital watermarking and information embedding,” *IEEE Trans. Inf. Theory*, vol. 47, no. 4, pp. 1423–1443, May. 2001.

[5] C. W. Honsinger, P. Jones, M. Rabbani, and J. C. Stoffel, “Lossless Recovery of an Original Image Containing Embedded Data,” *U.S. Patent 6 278 791 B1*, Aug. 21, 2001.

[6] B. Macq and F. Deweyand, “Trusted headers for medical images,” *presented at the DFG VIII-D II Watermarking Workshop*, Erlangen, Germany, Oct. 1999.

[7] I. K. Yeo, and H. J. Kim,” Modified Patchwork Algorithm: A Novel Audio Watermarking Scheme,” *IEEE Trans. Speech and Audio Process*., vol. 11, no. 4, pp. 381-386, Jul. 2003.

[8] G. Xuan, J. Zhu, J. Chen, Y. Q. Shi, Z. Ni, and W. Su, “Distortionless data hiding based on integer wavelet transform,” *IEE Electron. Lett*., vol.38, no. 25, pp. 1646–1648, Dec. 2002.

[9] M. U. Celik, G. Sharma, A. M. Tekalp, and E. Saber, “Reversible data hiding,” *in Proc. IEEE ICIP*, Rochester, NY, vol. 2, pp. 157–160, Sep. 2002.

[10] J. Tian, “Reversible data embedding using a difference expansion,” *IEEE Trans. Circuits Syst. Video Technol*., vol. 13, no. 8, pp. 890–896, Aug. 2003.

[11] A. M. Alattar, “Reversible watermark using difference expansion of triplets,” *in Proc. IEEE ICIP*, Barcelona, Spain, Sep. 2003, vol. 1, pp. 501–504.

[12] Z. Ni, Y. Q. Shi, N. Ansari, and W. Su, “Reversible Data Hiding,” *IEEE Trans. Circuits Syst.: Video Techno*., vol. 16, no. 3, pp. 354-362, Mar. 2006.

[13] S. Lee, C. D. Yoo, and T. Kalker, “Reversible Image Watermarking Based on Integer-to-Integer Wavelet Transform”, *IEEE Trans. Inf. Forensics Security*., vol. 2, no. 3, pp. 321-330, Sep. 2007.