Reversible Watermarking Based on Improved Patchwork Algorithm and Symmetric Modulo Operation

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Abstract. Modulo operations are often used in reversible watermarking scheme.However, the modulo operations would cause an annoying visual artifact similar to the "salt-and-pepper" noise when pixel value close to the maximally allowed value are flipped to zero and vice versa. To prevent the "salt-and-pepper" noise, the paper presents reversible watermarking scheme using improved patchwork and an improved modulo operation. The improved modulo operation called symmetric modulo operation effectively avoids "salt-and-pepper" noise by the reasonably reducing the flipping distance. Experimental results show that correctly watermark bits can be retrieved by the patchwork algorithm without the original image and that the original image can be restored perfectly while the perceptual degradation of the watermarked signal remained acceptable.

1 Introduction

In some applications, especially for some critical applications such as the fields of the law enforcement, medical and military image system, it is crucial to restore the original image without any distortions after the watermarked data are retrieved for any legal or other considerations. The watermarking techniques satisfying those requirements are referred to as the reversible watermarking.

Reversible watermarking puts emphasis on the reversible recovery of the original image and correctly extracts the watermark in order to judge whether the image has been attacked or modified. The concept of reversible watermark firstly appeared in the patent owned by Eastman Kodak[1]. Modulo operation is a kind of simply reversible operation. Fridrich et al[3] proposed another reversible watermarking data embedding scheme, which embeds data in the saved space of some losslessly compressed bit-planes in the spatial domain. Tian[5] proposed a reversible data embedding approach based on expanding the pixel value difference between neighboring pixels which will not overflow or underflow after the expansion .De Vleeschouwer et al[4] proposed a lossless data hiding algorithm based on patchwork theory.

The patchwork algorithm[2] is applied in the reversible watermark in order to correctly detect the watermark sequence without the original image. However, the methods are not satisfactory. Owing to the practice application, some image

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blocks can not satisfy the assumption the patchwork algorithm based on, which introduces the possibility of wrong judgment and reduces the embedding bits. The modulo operations[3] easily introduce the "salt-and-pepper" noise, which heavily impacts on and destroys the effect of the image.

The paper put forward an improved approach—symmetric modulo operation to resolve the problems mentioned above and use the improved patchwork algorithm successfully in reversible watermarking for images.

In section 2, some relevant knowledge are reviewed, in Section 3 embedding process and extracting process are presented respectively, in Section 4, we give the experimental results and Section 5 concludes the paper.

2 Relevant Knowledge

The patchwork is an excellent watermarking algorithm proposed for images [2]. Bender, Gruhl, Morimoto, and Lu proposed the core idea. The modulo operations are simply lossless operations. To describe our scheme later, some relevant knowledge of the patchwork algorithm and modulo operation is briefly introduced.

2.1 The Review of the Patchwork Algorithm

The algorithm is based on the following assumptions: (i) the sample populations are uniformly distribution.(ii) the sample means are all the same.

The two major steps in the algorithm are (i) choose two patches pseudorandomly and (ii) add the small constant value to the sample values of one patch and subtract the same value from the sample values of another patch . Mathematically speaking:

$$\alpha_i = a_i + \delta, \beta_i = b_i - \delta \quad a_i \in A, b_i \in B \tag{1}$$

Let S_n be defined as:

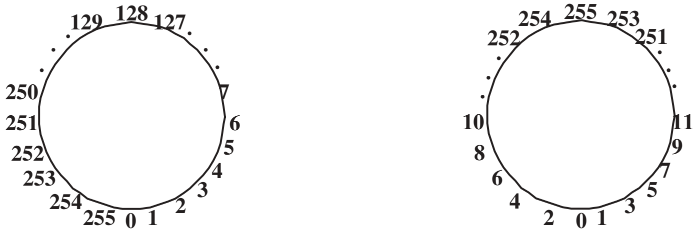
$$S_n = \sum_{i=1}^{n} (a_i - b_i) \quad a_i \in A, b_i \in B \tag{2}$$

According to the assumption the patchwork algorithm based on, the expected value of S_n is 0.

Let $S_n^{'}$ be defined as:

$$S_n^{'} = \sum_{i=1}^{n} ((a_i + \delta) - (b_i - \delta)) = 2n\delta + \sum_{i=1}^{n} (a_i - b_i) \quad a_i \in A, b_i \in B \tag{3}$$

From Equ.(3), we know that we can embed a watermark bit into the patch pair by slightly modifying the original sample values. The detection process starts with subtraction of the sample values between the patches. In extraction, we can detect whether the original image is watermarked or not by comparing $E[\alpha_i - \beta_i]$ with the threshold $M = n\delta$.



(a) (b)

Fig. 1. Modulo operations. (a) Traditional modulo 255 addition; (b) Symmetric modulo operation

2.2 The Review of Modulo Operations

The invertible modulo operations[3] from the above paragraph can be represented using the following permutation:0 → 1,1 → 2,...,254 → 255,255 → 0 shown in Fig. 1.(a).The formula for this invertible addition is:

$$j \bigoplus (k) = C[j/C] + mod((j+k), C) \tag{4}$$

where $\lfloor x \rfloor$ stands for the integer part of x and C is the cycle length. The invertible subtraction is defined as

$$j - k = j \bigoplus (-k) \tag{5}$$

where i is the grayscale value, k is the concrete watermarking value, $\bigoplus$ is modulo operation.

3 Proposed Reversible Watermarking Approach

A basic frame of our proposed scheme is presented in Fig.2, based on the improved patchwork algorithm and symmetric modulo operation, where x is an original image block, x_w is the watermarked version of x, Key is a secret key, WM represents the watermark sequence.

x_p is represented as the image block after pseudo-randomly selection process which consists of the patch A and B. x_{oe} is represented as the image block after the patch A and B are divided into four sets A_o ,A_e ,B_o ,B_e . A_o which the positions tagged with "x" represents consists of odd pixel values, while A_e which the positions tagged with "*" represents consists of the even pixel values . B_o ,B_e are similar to A_o ,A_e. If watermark bit is equal to 1, the grayscale values of A rotate clockwise C times and the grayscale values of B rotate anti-clockwise C times according to symmetric modulo operation and constant embedding level C, The patchwork B is similar to the patch A.

3.1 Symmetric Modulo Operation

From the formula [4], grayscale 255 is flipped to grayscale 0 and vice versa. Those flipping pixels introduce the "salt-and-pepper" artifact. Although the modulo 225 addition may completely restore the original image, but it would cause the

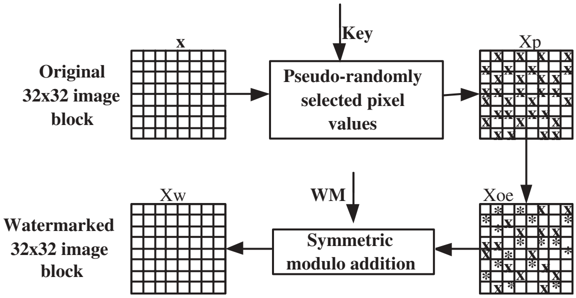


Fig. 2. Embedding process for 32x32 block

heavily visual distortion, and those flipping points would increase the possibility of wrong judgment which is analyzed in detail in the Section 3.3

Modulo operation is represented as the following permutations:0 $\rightarrow$ 1,1 $\rightarrow$ 3,$\cdots$,253 $\rightarrow$ 255,255 $\rightarrow$ 254,$\cdots$,4 $\rightarrow$ 2,2 $\rightarrow$ 0 ,shown in Fig.1.(b). Odd and even grayscale values symmetrically spread around the circle. The method may guarantee all neighbors correspond to close grayscale values. It prevents "salt-and-pepper" artifact.

3.2 Improved Patchwork Algorithm

The original patchwork algorithm adds the small constant value δ to the sample values of one patch and subtracts the same value δ from the sample values of another patch, but the symmetric modulo operation would make odd pixel values add δ and even pixel values subtract δ respectively in the patch A and B. The value of $E[\alpha_i - \beta_i]\alpha_i \in A, \beta_i \in B$ is nearly not changed. The original patchwork algorithm combining with symmetric modulo operation do not work, so the paper improves the patchwork algorithm. The method is presented as follows:

Calculate the sample means $\overline{a_o} = 1/n \sum_{i=1}^{n} (a_o)$,$\overline{a_e} = 1/n \sum_{i=1}^{n} (a_e)$,$\overline{b_o} = 1/n \sum_{i=1}^{n} (b_o)$,$\overline{b_e} = 1/n \sum_{i=1}^{n} (b_e)$ and of sets A_o,A_e ,B_o ,B_e and the difference d_1 of the sample means between the setA_o ,A_e and the difference d_2 between B_o,B_e. Owing to patch A and patch B are pseudo-randomly selected, the expected value of the difference $(d_1 - d_2\ )$ is 0 whatever A or B is according to the original patchwork algorithm. After embedding process completed, generally d would become larger and is larger than $8 \times C$.

The extracting process which is similar to the embedding process is presented in Fig. 3. Here, introduce the extracting method: first calculate the difference of the sample means between the set A_o and A_e, and the difference d_2 betweenB_o andB_e .Compare the value $d = (d_1 - d_2)$ with threshold M = 4*C (constant embedding level). When $d > M$, "1" is embedded. When $d < -M$, "0" is embedded. Second by watermark bits, the original image is reversibly restored. If watermark bit is equal to 1, the grayscale values of A rotate anti-clockwise C times and the grayscale values of B rotate clockwise C times according to symmetric modulo operation to restore the original image.

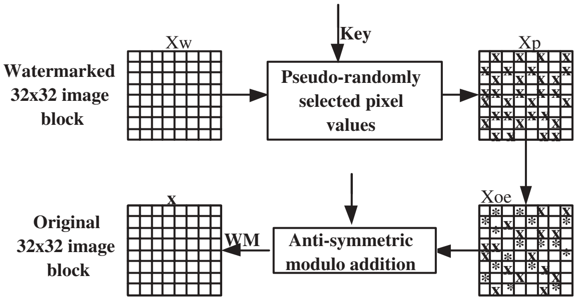


Fig. 3. Extracting process for 32x32 block

3.3 The Analysis of the Problematic Blocks

In general, the mean of the sample pixels belonging to patch A are close to the mean of the sample pixels belonging to patch B before embedding. This is highly probable, since the blocks have equal sizes and are pseudo-randomly selected. But in practical application, some image blocks can not satisfy those assumptions, that is the difference of the sample mean values between patch A and patch B is larger. Even after embedding watermark, the distance is too large to correctly detect the watermark. Now the paper takes an example to explain that drawback. Assume $w_k = 0$. Calculate $S_n^{'} = \sum_{i=1}^{n}((b_{1i} + \delta) - (b_{0i} - \delta)) = 2n\delta + \sum_{i=1}^{n}(b_{1i} - b_{0i}) \quad b_{0i}, b_{1i} \in B$. Assume $\sum_{i=1}^{n}(b_{1i})$ is less than $\sum_{i=1}^{n}(b_{0i})$ and the difference is very larger. If$(\sum_{i=1}^{n}(b_{1i} - b_{0i})$) is less than ($-\delta n$), then $(2\delta n + \sum_{i=1}^{n}(b_{1i}) < \delta n)$. Where $\delta n$is equal to the threshold value M.

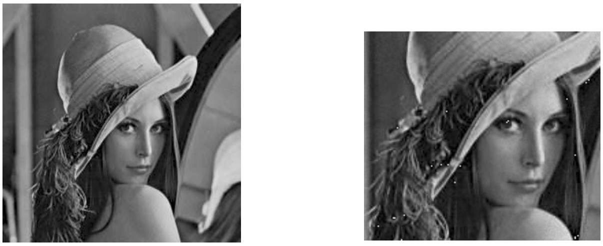
According to the above analysis, $S_n^{'}$is less than threshold value, so the watermark sequence can not be correctly extracted . The paper calls those blocks as bad blocks. If the number of bad blocks is very larger, it would heavily impact the number of the embedding bits. Add the value of δ to reduce the situation, but the visual quality would become bad, so δ can not be too larger. To correctly detect these blocks, the receiver needs additional knowledge to reverse the embedding.

If the difference between b_{1i},b_{0i} is fewer, but after embedded watermark information, the difference is still fewer. For such blocks, the method of resolving the problem is not to embed watermark. When extracted, one can reverse the watermark and the original image without additional knowledge for the receiver. We call such blocks as useless blocks.

4 Experimental Results

The test 256-grayscale image "Lena" with size 256×256 is divided into 32×32 pixel block.

From the above Fig. 4, you may easily notice those flipping points, which cause the salt-pepper-noise. Those heavily influence the quality of the image.For



(a) (b)

Fig. 4. Original image and watermarked image with modulo 255 addition. (a) The original image ; (b) A part of the watermarked image

Table 1. It shows the results with the modulo 255 addition and the patchwork algorithm. It partitions the distribution of the image blocks into three categories. The category contains the regular blocks, the second is the bad block avoided by adding the embedding depth. and the last blocks can not bring nothing to capacity.The embedding level is the constant C

Image	*Block Size*	*Regular Size*	*Bad Size*	*useless Size*
Lenna	$16 \times 16(C = 4)$	219	24	13
	$32 \times 32(C = 4)$	60	0	4

those disadvantages, we present an improved method: symmetric modulo operation. The method may eliminate "salt-and-pepper" noise.

Fig. 5 and Table 2 show the experimental results of adopting the symmetric modulo operation and improved patchwork algorithm. There are not any flipping points in Fig. 5. The visual quality is largely improved.

(a) (b)

Fig. 5. It shows the watermarked image with the different embedding levels by the patchwork algorithm and symmetric modulo operation. The constant C is the fixed embedding level. (a) Watermarked image (C =2); (b) Watermarked image (C = 4)

Table 2. Number of blocks used to infer the capacity. The last two columns respectively correspond to the regular blocks and the bad blocks

Image	*Block Size*	*Regular Size*	*Bad Size*	*useless Size*
Lenna	32×32(C=2)	62	2	0
	$32 \times 32(C = 4)$	0	0	0

5 Conclusion

The paper applies the patchwork algorithm and modulo 255 addition to reversibly restore original image, but the methods have some drawbacks, for example "salt-and-pepper" noise and bad blocks. In order to resolve that disadvantage, the paper presents symmetric modulo addition by constant embedding level in advance to avid the "salt-and-pepper". With larger embedding level, for instance from 2 to 4, the number of the bad blocks become fewer or none, but the quality of the image become a little worse. In practice, we may choose different embedding level for different situation.

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