LETTER

Lossless Data Hiding Based on Companding Technique and Difference Expansion of Triplets

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SUMMARY A reversible data hiding scheme based on the companding technique and the difference expansion (DE) of triplets is proposed in this paper. The companding technique is employed to increase the number of the expandable triplets. The capacity consumed by the location map recording the expanded positions is largely decreased. As a result, the hiding capacity is considerably increased. The experimental results reveal that high hiding capacity can be achieved at low embedding distortion.

key words: *reversible watermarking, companding technique, DE of triplets*

1. Introduction

Tian expanded the differences between two neighboring pixel values to embed a bit without causing overflows/underflows [1]. Alattar used the difference expansion of triplets to embed two bits into each triplet [2]. Xuan et al. embedded data into the high-frequency wavelet coefficients by the companding technique and used a preprocessing to avoid the overflow/underflow caused by watermark embedding [3].

For each expandable triplet in Alattar's, if its two differences are both less than a predefined threshold, it is expanded during embedding. If this threshold is small, a location map recording these expanded positions can hardly be compressed into a short bitstream. As a result, it consumes a large part of the available capacity and leads to a low hiding capacity. To achieve high hiding capacity even at small threshold without decreasing PSNR value, we utilize a quantized compression function to compress those expandable differences larger than the threshold into small values. The advantage is that we can considerably increase the number of expanded triplets while retain low embedding distortion. Thus, the location map can be efficiently compressed due to significant difference between the possibilities for being expanded and non-expanded triplets. As a result, the hiding capacity is effectively increased.

2. Data Embedding

In an 8-bit grayscale image I, every three adjacent pixels are grouped into a triplet denoted by $t = (u_0, u_1, u_2)$ in raster order.

The forward integer transform $T(\cdot)$ [2] for the triplet t is defined as

$$v_0 = \left\lfloor \frac{u_0 + u_1 + u_2}{3} \right\rfloor,\ v_1 = u_2 - u_1,\ v_2 = u_0 - u_1 \qquad (1)$$

The inverse integer transform $T^{-1}(\cdot)$ is given by

$$u_1 = v_0 - \left\lfloor \frac{v_1 + v_2}{3} \right\rfloor,\ u_0 = v_2 + u_1,\ u_2 = v_1 + u_1 \qquad (2)$$

For each t, its two difference values v_1 and v_2 serve as inputs of a quantized compression function C_Q [3] given by Eq. (3) to create their corresponding outputs v_{Q1} and v_{Q2}.

$$C_Q(x) = \begin{cases} x & |x| < T \\ \mathrm{sign}(x) \times \left(\left\lfloor \frac{|x| - T}{2} \right\rfloor + T \right) & |x| \geq T \end{cases} \qquad (3)$$

where x is used to denote v_1 or v_2. In this paper, we set the same integer threshold T for v_1 and v_2.

The expansion function is defined as

$$E_Q(x) = \begin{cases} x & |x| < T \\ \mathrm{sign}(x) \times (2|x| - T) & |x| \geq T \end{cases} \qquad (4)$$

For $|x| < T$, its companding error $r = |x| - |E_Q(C_Q(x))|$ is zero. While for $|x| \geq T$, $r \in \{0, 1\}$, and accordingly, it is required to be collected as a part of embedded data to reconstruct the original image.

Each t is classified into one of the following three categories: Expandable Set (ES), Changeable Set (CS), and Nonchangeable Set (NS).

For each t, $b_{1,2} = 0, 1$, if $\tilde{v}_1$ and $\tilde{v}_2$ given by Eq. (6) satisfy Eq. (5), then t is classified into ES.

$$(\tilde{v}_1 + \tilde{v}_2) - (3v_0 + 2) \leq \min(0, 3\tilde{v}_1, 3\tilde{v}_2) \qquad (5)$$

$$(\tilde{v}_1 + \tilde{v}_2) - 3(v_0 - 255) \geq \max(0, 3\tilde{v}_1, 3\tilde{v}_2)$$

$$\tilde{v}_1 = 2v_{Q1} + b_1, \tilde{v}_2 = 2v_{Q2} + b_2 \qquad (6)$$

For $t \notin ES$, $b_{1,2} = 0, 1$, if its $\tilde{v}_1$ and $\tilde{v}_2$ based on Eq. (7) satisfy Eq. (5), then t is considered into CS.

$$\tilde{v}_1 = 2\left\lfloor \frac{v_1}{2} \right\rfloor + b_1,\ \tilde{v}_2 = 2\left\lfloor \frac{v_2}{2} \right\rfloor + b_2 \qquad (7)$$

To reconstruct v_1 and v_2, their LSBs must be kept as a part of embedded data and should be collected into C.

The other triplets belong to NS.

For each t in ES, if $|v_1| < T$, then v_1 will be classified

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into S_1. Otherwise, v_1 belongs to S_2. There is similar classification for v_2. Since each t has two difference values, then $2\|ES\| = \|S_1\| + \|S_2\|$, where the operator $\|\cdot\|$ represents the cardinality of a set.

A location map is created by assigning '1' to all those triplets in ES and '0' to the others. Then it is losslessly compressed by an arithmetic encoder into a bitstream $\mathcal{L}$ with an unique EOS symbol at its end.

For each v in S_2, its r is collected into another bitstream $\mathcal{R}$. This means that $\|S_2\| = \|\mathcal{R}\|$. Thereby, the embedding capacity is $2\|ES\| - \|\mathcal{L}\| - \|\mathcal{R}\| = \|S_1\| - \|\mathcal{L}\|$ (bit). Note that the companding technique is applied to considerably increase $\|ES\|$. When twenty standard images are used as test images, $\|ES\|$ is very close to the total number of the triplets at the threshold T selected from 3 to 8. As a result, in our method, a small value $\|\mathcal{L}\|$ is obtained and the embedding capacity is considerably increased. While in Alattar's, if the threshold is selected as 8, the possibility of '1' in the location map congregates in the range of 30% to 70% for most of the test images. This leads to that the location map can not be efficiently compressed.

$\mathcal{L}$, C, $\mathcal{R}$ and the payload are embedded into the triplets according to the classification. Finally, $T^{-1}(\cdot)$ is applied to produce the marked image I_w.

3. Data Extraction and Recovery

Pixels in image I_w are grouped into triplets in the same way as in embedding. $T(\cdot)$ is applied to each triplet to get its transformed $t' = (v_0, \tilde{v}_1, \tilde{v}_2)$.

For each t', according to Eq. (7), if the output values associated with the input values $\tilde{v}_1$, $\tilde{v}_2$ satisfy Eq. (5), then it is classified into CH. Otherwise, it belongs to NS.

The LSBs of $\tilde{v}_1$ and $\tilde{v}_2$ of t' in CH are collected into a bitstream $\mathcal{B}$. By identifying EOS in $\mathcal{B}$, the bits from the start until EOS are decompressed as the location map. For each t' in CH, if its location is associated with '1' in the location map, t' is classified into set $\tilde{ES}$. Otherwise, it belongs to set $\tilde{CS}$. The bits after EOS in $\mathcal{B}$ are identified as $\mathcal{R}$, C and the payload.

For each t' in $\tilde{ES}$, its original difference values v_1 is equal to v_{Q1} for $|v_{Q1}| < T$, while for $|v_{Q1}| \geq T$, $|v_1| = |E_Q(v_{Q1})| + w$, where $v_{Q1} = \left\lfloor \frac{\tilde{v}_1}{2} \right\rfloor$, $w \in \mathcal{R}$.

For $t' \in \tilde{CS}$, $w \in C$, $v_1 = 2 \times \left\lfloor \frac{\tilde{v}_1}{2} \right\rfloor + w$.

The restoration for v_2 is similar to that of v_1. Finally, $T^{-1}(\cdot)$ is applied to reconstruct I.

4. Experimental Results

The capacity vs. distortion comparisons among our method, Tian's, Alattar's and Xuan's on 'Baboon' and 'Build' are shown in Fig. 1 and Fig. 2. The proposed method is superior to Alattar's and Tian's (refer to Fig. 1 and Fig. 2). For 'Baboon' image, there is almost no pixel distributed near the high end and low end of the gray-level spectrum, ours is slightly better than Xuan's. For many images such as

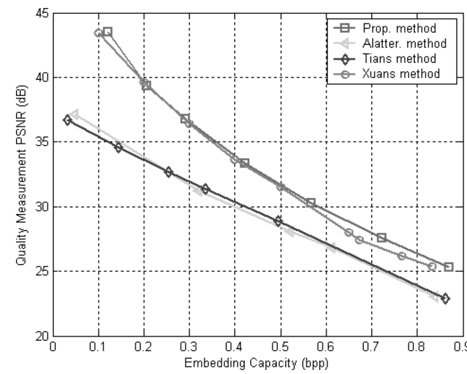

Fig. 1 The capacity vs. distortion comparison on 'Baboon.'

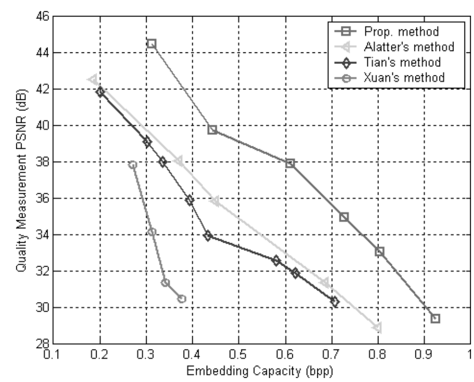

Fig. 2 The capacity vs. distortion comparison on 'Build.'

'Build' with pixels distributed across the entire gray-level spectrum, our proposed method further outperforms Xuan's.

5. Conclusions

A novel reversible data hiding scheme based on the companding technique and the DE of triplets is presented in this paper. The embedding capacity is largely increased with the incorporation of the companding technique. From the experimental results, it can be seen that our method outperforms Tian's and Alattar's.

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