Mapping Based Reversible Watermarking

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Abstract: The set of pairs of pixels is partitioned into disjoint groups of equal number of pairs. Furthermore, a subset of pairs of pixels is selected and each pair is uniquely associated with a group of the partition. If the size of the groups is m, $\log_2 m$ bits of data can be embedded into an image pair by replacing it by the pairs of a group. As long as at detection one can find if a pair was replaced or not, the transform is reversible. Hence a reversible watermarking scheme is obtained by embedding together with the watermark the information needed to locate the transformed pairs. The paper discusses how to select the subset of pixel pairs and the partition in order to obtain high capacity watermarking schemes. It is also shown that a recently proposed reversible scheme is based on this principle. Due to its flexibility, the general scheme is expected to introduce less distortion. The experimental results obtained so far are promising.

Key words: embedding bit-rate, integer mapping, reversible watermarking

INTRODUCTION

Reversible watermarking (also known as lossless, distortion-free, invertible) removes completely the watermark and exactly recovers the original signal/image. This subject is of considerable interest in some special domains where no loss of information is accepted.

So far, several reversible watermarking approaches have been proposed [FRI 02] [TIA 03] [ALA 04] [CEL 05] [VLE 03] [COL 05] [COL 06b]. Most of them must apply lossless data compression to gain space for data embedding [FRI 02] [TIA 03] [ALA 04] [CEL 05]. Among these, the highest embedding bit-rates are provided by the generalized LSB embedding [CEL 05] and notably, by the difference expansion schemes [TIA 03] [ALA 04] [KAM 05].

There are also reversible watermarking schemes that do not need explicit data compression algorithms. We mention the circular histogram interpretation [VLE 03] and the simple reversible watermarking schemes [COL 05] [COL 06b].The drawback of histogram based scheme, as well as of some other schemes where data is embedded on some statistics taken over blocks of pixels, is their low embedding capacity. By the contrary, the simple schemes, [COL 05] [COL 06b], provide high-capacity embedding bite-rates. They outperform the generalized LSB embedding scheme and they provide almost similar bit-rates as the difference expansion schemes. The simple schemes are of very low computational complexity. A weakness of these simple schemes is the distortion introduced by the watermarking, especially at high bit-rates. While at bit-rates lower than 0.5 bpp, the watermarking is imperceptible, as the bit-rate increases, the distortions increases as well and the marked images look noisy. It should be noticed that, since the watermarking is reversible, at detection the authorized party can recover the original image without any distortion.

The simple schemes, [COL 05] [COL 6b], are based on some integer invertible transforms defined on groups of n pixels, where n>1. Groups obeying some simple constraints are transformed and furthermore, data is embedded into the transformed groups. The transforms induce some properties allowing reversible data embedding. For the original simple scheme [COL 05] [COL 6a], the transform is robust in the sense that the inverse transform gives exact results even if the LSBs of the transformed groups are lost. Thus, space is created into the LSB plane for data insertion. In order to retrieve the pairs that have been transformed, a location map should be stored together with the watermark. The location map needs one bit for each group of n pixels. Furthermore each transformed group provides n-1 bits for data embedding. The scheme works if there are more than 1/n transformed groups from the total number of groups. For groups of two pixels, the scheme provides at maximum 0.5 bpp per iteration. For n>2, the scheme may provide in a single iteration more than 0.5 bpp, but the bit-rate per iteration is bounded by 1 bpp. In order to increase the bit-rate, multiple iterations are performed. Usually, for natural images, the bit-rate provided for data hiding is of the order of 1.5 bpp.

The high-capacity simple scheme, [COL 6b], works on pairs of pixels, but uses a slightly different transform. Pairs obeying some simple constraints are transformed in order to satisfy a congruence equation. By adding some correction data, the not transformed pixel pairs are enforced to obey the same equation, too. By simple additions, the watermark together with the correction data is embedded into the transformed pixels. After watermark insertion, only the not transformed pixel pairs satisfy the congruence equation. Hence, at detection, the transformed pairs can be localized. Finally, the watermark and correction data can be extracted and the exact recovery of the original image follows by inverse transform. The high capacity scheme can provide, in a single iteration, more than 1 bpp.

This paper investigates a general mapping based reversible watermarking. The proposed watermarking scheme can be seen as an extension of the simple reversible schemes discussed above [COL 05] [COL 06b]. The new watermarking scheme is intended to preserve the high capacity and the low cost of the simple schemes and besides, to introduce less distortion. The principle of the watermarking is discussed in Section 1. The watermarking scheme is presented in Section 2. An example of reversible watermarking is analyzed in Section 3. Conclusions are drawn in Section 4.

1. Watermarking Principle

Let us first analyze the high capacity reversible scheme [COL 06b] and then, introduce the principle of the proposed general mapping watermarking. As said above, the scheme transforms pairs of pixels, (x,y), into pairs of pixels, (X,Y). The transform T is given by the equations:

$$\mathbf{X=(p+1)x-py;\ Y=(p+1)y-px} \qquad (1)$$

where p is an integer. The transform used in [COL 05] is recovered from equations (1) by taking the integer p equal to 1, transform which is further extended in [COL 06a] for groups of n pixels.

Let [0,L-1] be image graylevel range, i.e., x, y, X, Y are integers in [0,L-1].Conditions to avoid pixel overflow or underflow are imposed:

$$0\leq X\leq L-1;\ 0\leq Y\leq L-1 \qquad (2)$$

From (2) it appears that the transform is not defined on the entire integer grid [0,L-1]x[0,L-1], but only on a subset. In the plane xy, equations (2) define a rhombic subdomain located along the main diagonal of [0,L-1]x[0,L-1]. Let D be the set of pixel pairs corresponding to the rhombic subdomain. The subdomain is transformed by T in parallel lines, parallel with the diagonal of [0,L-1]x[0,L-1]. The distance on the integer grid between the lines on horizontal (equivalently, vertical) direction is 2p+1.

The scheme provides an embedding capacity of $\log_2(2p+1)$ bits per transformed pair. This is done by adding an integer ranging in [0,2p] to the first pixel of any transformed pair. Hence the data embedding is performed by transforming a pair of pixels belonging to D and then by selecting a pair from [0,L-1]x[0,L-1] located on vertical direction in the neighborhood of the transformed one.

In fact, the reversible watermarking scheme partitions the integer grid [0,L-1]x[0,L-1] in groups of 2p+1 integers located on vertical direction. This corresponds to a partition of the entire pairs set in groups of 2p+1 pairs. In each group, there is only a single pair (X,Y) such that (X,Y)=T(x,y), where (x,y) belongs to D. At detection, once a pair is identified as a transformed one, the group of 2p+1 pixel pairs of the partition is identified, too. The embedding data is extracted and then, by inverting equations (1), the original pair of pixels is recovered. Some additional data, like a location map, should be embedded together with the watermark in order to provide, at detection, the information needed to identify the transformed pairs.

The scheme provides high capacity data embedding since there is a great number of image pixel pairs belonging to D. This is due to the fact that in homogenous areas pixels have graylevels close to each others and the pairing is performed by taking adjacent pixels. Therefore a large number of pairs are located along the diagonal of [0,L-1]x[0,L-1].

To conclude, a reversible watermarking scheme is obtained by defining a partition of the set of graylevel pairs in groups of m pairs and by defining a certain one to one mapping, too. Each pair of a group of m can encode an integer in the range [0,m-1]. Furthermore, pixel pairs are transformed according to the mapping and data is embedded by taking the appropriate pair within the group of m. Such a scheme provides $\log_2 m$ bits per transformed pair.

With respect to the hiding bit-rate, the reversible watermarking scheme is of interest if the mapping is defined on a subset which is very well represented among the pairs obtained by grouping image adjacent pixels. This is exactly what the scheme of [COL 06b] is doing. As discussed above, the equations (1) define the mapping between the pixel pairs set defined by equations (2) and some pairs of [0,L-1]x[0,L-1] set. The equations (1,2) are simple and give an elegant setting of the reversible watermarking.

The general framework proposed in this paper allows more flexibility, since no a priori constraints exists neither for the mapping nor for the partition. By a better selection of the partition, we expect to obtain less distortion at the same bit-rate than for the scheme of [COL 06b].

2. Reversible Watermarking Scheme

2.1. The mapping

The essential element of the reversible watermarking scheme is the mapping. The mapping is defined on a certain subset D of entire set of pairs, the Cartesian product [0,L-1]x[0,L-1]. Let N be the number of pixel pairs of D.

Let m be the number of pairs of the groups. Obviously, the set of pixel pairs [0,L-1]x[0,L-1] has L^2 distinct elements. In order to have a one to one mapping, m should be less than L^2/N. It should be noted that larger m, greater the bit-rate provided by the scheme. Meantime, a large m will increase the distortions introduced by the watermarking. Examples for different values of m will be given in the next section.

Once m selected, we define the partition of the set of pairs in groups of m. For the case $m=r^2$ (or similarly, m=rq), the set [0,L-1]x[0,L-1] can be simply partitioned in squares of size rxr or, generally, in rectangles of size rxq). For the case arbitrary m, we consider the following procedure. Since L is generally a power of two (L=256 for 8 bit graylevel images), the set [0,L-1]x[0,L-1] can be traversed by a Peano curve. We mention that Peano curve achieves a good compromise between one-dimensional and two-dimensional neighborhoods – in the sense that, broadly speaking, points that are nearby in the two-dimensional domain are nearby along the Peano curve and conversely. Peano curve introduces an ordering on the two-dimensional set of pixel pairs. Then, starting from an endpoint of the curve and following the curve, the groups of m pairs are constructed. The procedure ensures that the pairs grouped together have quite similar graylevel values for each component.

For each group, a representative pair is selected. First the pairs of the group are averaged and then, the representative is selected as the pair having the minimum Euclidean distance to the average.

The mapping between D and the N representative pairs of [0,L-1]x[0,L-1] is further determined by minimizing the mean squared error between the pairs of D and the corresponding representatives. Finally, the encoding of embedded data on each group is defined. We consider that selecting the representative pixel pair means the encoding of ‘0’. The other (m-1) pairs of each group encode the integers from ‘1’ to ‘m-1’. Thus, by selecting a certain pair within the group of a transformed pair, a codeword in [0,m-1] is embedded. Now, the mapping is completely defined.

2.2. Marking

The marking proceeds as follows:

1. Partition entire image in pairs of pixels;
2. Transform the pairs belonging to D according to the mapping and create a location map accordingly;
3. Embed the watermark by replacing the transformed pair with the pair of the group corresponding to the integer codeword to be inserted.

Image partition in pairs of pixels can be made along rows, columns or any space filling curve. The only constraint imposed for the pairing is to have adjacent pixels.

The watermark consists of the location map, the payload and some data to validate the integrity of the watermark. For watermarking integrity validation, a cyclic redundancy check (CRC) is sufficient.

An improvement in data hiding capacity can be achieved by storing only a partial location map. If after the mapping and the data encoding steps the resulted pair still belongs to D, then such a pair can be non ambiguously identified at detection. Therefore it is not necessary to use a bit in the location map to record its status. Let us suppose that a scanning order is defined. Then, the data embedding step will not start with the first pair in the scanning order which belongs to D, but with the first pair which can be non ambiguously identified at detection. The embedding will continue with the second such pair and so on. After all such pairs are processed, the embedding is performed, in the scanning order, for the skipped pairs.

2.3. Detection and original recovery

The detection procedure immediately follows. The pairs are taken in the scanning order and the pairs non ambiguously detectable are first processed. For each pair, the group to which the pair belongs is first found. Then the embedded data is decoded. At marking, data embedding starts with the location map. Therefore, at detection, the bits of the location map are first recovered. After the end of the set of non ambiguously detectable pairs, the decoding goes on in the scanning order according to the location map. The identified pairs are decoded and the remaining bits of the location map and the payload are extracted.

After watermark extraction, the original image recovery follows. For each transformed pair, the representative pair of the group is identified and then inverted to recover the original pixel values.

3. An example

A domain D constituted of 4093 pairs of pixels has been considered. As discussed in Section 1, pairs close to the diagonal of [0,L-1]x[0,L-1] have been selected. In the xy plane, the shape of the domain is an ellipse, as shown in Fig. 1. For mappings of D on [0,L-1]x[0,L-1] are derived for m=4, 8, 12 and16, respectively.

Fig.1. *Representation of the mapping domain D.*

Fig. 2. *Original test image.*

Fig.3. *Marked image for m=4: 0.64 bpp at 32.82 dB.*

Fig. 4. *Marked image for m=8: 0.99 bpp at 25.93 dB.*

Fig. 5. *Marked image for m=12: 1.21 bpp at 22.45dB.*

Examples of reversible watermarking are provided for the test image Lena. The original image is shown in Fig. 2. The embedding bit-rate and the quality of the watermarked image are further investigated. In this experiment, only a single watermarking stage for each one of the mappings is considered.

The watermarked version for m=4 (Fig. 3) provides a data embedding bit-rate of 0.65 bpp. The reported bit-rate takes into account only the effective data space available for storing the payload, i.e., after the embedding of the location map. The PSNR of the marked image is of 32.82 dB.

The watermarking scheme obtained by considering the mapping for m=8 provides, for the same test image, a bit-rate of 0.99 bpp at a PSNR of 25.93 dB. The marked image is shown in Fig. 4. Furthermore, for m=12, the bit-rate is 1.21 bpp at a PSNR of 22.45 dB (Fig. 5). Finally, a bit-rate of 1.37 bpp at a PSNR of 19.62 dB is obtained in the case m=16.

With respect to the embedding bit-rate, the results are similar to the one reported in [COL 06b]. Similar to the high capacity watermarking of [COL 06b], the scheme can provide in a single iteration more than 1 bpp (as in the case m=3 and m=4). Furthermore, by chaining multiple watermarking steps, an increase of the embedding bit-rate can be obtained. The mathematical complexity of the watermarking is low: no additional data compression is needed.

The watermarked image shown in Fig. 3 provides 0.64 bpp at a PSNR of 32.82 dB. This appears to be a significant improvement with respect to [COL 06], where a bit-rate of 0.49 bpp was obtained for the same test image at a PSNR of 29 dB. As the bit-rate increases, the distortion increases, too.

4. Conclusions

A general framework for reversible watermarking was proposed. The set of pairs of pixels is partitioned into disjoint groups of m pairs. Meantime, a subset of pairs of pixels is selected and each pair is uniquely associated with a group of the partition. Then $\log_2 m$ bits of data can be embedded into an image pair by replacing it with the pairs of its corresponding group. The paper discusses how to define such a partition and how to select the subset of pixel pairs in order to derive high capacity reversible schemes. The derived schemes are of low mathematical complexity. No additional data compression is needed. The high capacity reversible watermarking [COL 06b] is a particular case of mapping based reversible watermarking schemes.

By an appropriate choice of the partition, the general approach introduces less distortion at the same embedding bit-rate. Such an example is provided. The results obtained so far are promising. More experimental results will be provided in the full paper version.

Further mappings and partition strategies are under investigation. The objective is to improve the quality of the marked images for high embedding bit-rates.

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