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Reversible Image Watermarking: A Review

Jincy J. Fernandez
Assistant Professor, Department of Computer Science and Engineering, Rajagiri School of Engineering and Technology,Cochin, Kerala, India

ABSTRACT

With the dawn of easiness in manipulating and transferring digital data in today's world, copyright protection and content authentication has become two serious issues / problems to the content owners. One solution to this problem is to embed watermark in the digital data, i.e. Digital watermarking. But in some applications, in addition to the extraction of watermark, the recovery of the original image is also essential. Reversible watermarking is a proven solution to this issue, where both watermark and original image can be recovered. This paper gives a detailed review on various currently existing techniques of reversible watermarking.
Keywords: Least Significant Bit (LSB), Copyright protection, Watermarking, Reversible Watermarking.

I. INTRODUCTION

Today, when data is readily available on internet for public access, this also rings in a hidden danger that these data can be used for irrelevant activities. As a solution to this problem, Digital watermarking ([1], [2]) can be used, which embeds some useful information into multimedia data such as audio, image and video. The two main categories of digital watermarking are robust watermarking and fragile watermarking. Robust watermarking is mainly focused on copyright protection whereas fragile watermarking is focused on content authentication. Even though one of the basic properties of digital watermarking is its imperceptibility, but somehow the original data gets modified by embedding a watermark.

In traditional watermarking, even though there is degradation in the original image and also the restoration of the original image is not possible, recovery of the watermark with minimum distortion was the major concern. But while considering sensitive images such as military images and medical images, not even a slight change in the pixel values is desirable as it can seriously affect the credibility of the original data. So in such applications, traditional approach does not suit well because the original image needs to be restored with good quality. Reversible watermarking plays a vital role in such applications where the original data can be restored when the digital content is authentic. The concept of reversible watermarking method was introduced by Honsinger et al. [3]. Reversible watermark can be considered as a type of fragile watermark. The main objective of reversible watermarking is to embed the information without any kind of distortion. Once the embedding area is selected, most of the reversible watermarking techniques use lossless data compression on the pixel values in the embedding area.

The organization of this document is as follows. Section II contains Basic definitions. Section III deals with detailed review on various reversible watermarking techniques. Section IV gives an insight of various applications where reversible watermarking is used and finally Section V presents the Conclusion.

II. BASIC DEFINITIONS

Types of watermark

A. Based on the media where watermark is embedded

1. Text Watermarking: Text is considered as the watermark and can be embedded in to an image [4].
2. Image Watermarking: Image is considered as the watermark and can be embedded in to a cover image [5].
3. Audio Watermarking: Audio signals are embedded in to an audio clip [6].
4. Video Watermarking: Video clips are embedded in to a cover video [7].

B. Based on the perceptibility of watermark

1. Visible watermark [8]:A *visible* watermark can be perceived with human eyes, where a visible semi-transparent text or image overlaid on the original image.
2. Invisible Robust watermark [8]: are those watermarks which will not change even if the watermarked image is modified or manipulated.
3. Invisible Fragile watermark [8]: are those watermarks which will change even if the watermarked image is modified or manipulated.

C. Based on the data needed for extracting watermark

1. Informed watermarking: The original cover image is needed to extract the embedded watermark.
2. Blind watermarking [9]: It is not required to have the cover image for the extraction of watermark.

III. TECHNIQUES ON REVERSIBLE WATERMARKING

A. Difference Expansion based Approaches

1) Difference Expansion: In this scheme [10], features of the original image are extracted in order to create space for embedding data bits. Firstly, the image is decorrelated by applying 1- D Haar wavelet transform where the average and differences of the adjacent pixels are computed. The data bit is embedded by appending it to the LSB of the difference. Large amount of data can be embedded with marginal distortion. The disadvantage of the technique is that since it uses LSB replacement, the actual LSB is modified in the embedding process.

2) Difference Expansion with Histogram Shifting and Overflow Map: After decomposing the image into differences and integer averages, the changeable (C) and the expandable locations are determined and a 2-D overflow map is formed with expandable locations. Auxiliary information is generated by concatenating lossless compressed overflow map and a header segment [11]. The selection of operating threshold is done in such a way that it has to satisfy the criteria that the total number of locations that comprise the selected bins is at least as large as the total number of bits embedded by expansion embedding technique.

The bit stream to be embedded is generated by concatenating auxiliary information, saved LSBs and the payload. Saved LSB means LSB's of the differences of the changeable locations in E_e, where E_e is the set of expandable locations that comprise the selected bins. And this bit stream is embedded into the changeable locations.

During the extraction process, the differences and integer averages of the watermarked image are computed and the embedded bit stream is extracted after identifying the changeable locations.

3) Difference Expansion with Histogram Shifting and Flag Bits: In this approach [11], flag bits are used to identify locations. When compared with the overflow map approach, this scheme differs in two aspects:

- The auxiliary information comprises of header segment and flag bits; instead of using overflow map.
- The operating threshold is determined recursively because it depends on the number of flag bits.

B. Integer Wavelet Transform Approach

In this scheme [12], the grayscale valued triplet of a color pixel undergoes reversible color conversion transform for mapping to integer valued triplet in order to get distortion free original content. The reversible color conversion can be omitted for grayscale images. An Integer Wavelet Transform (IWT) is applied to the luminance component. An expandable and changeable grayscale valued pair is defined in order to increase the bit length of the binary representation without causing any underflow or overflow problem. While removing the watermark to retrieve the original un-watermarked image, the location of expanded difference numbers are to be known to the detector. A location map is defined with bits 1 and 0 representing whether it is expanded or not respectively. The location map further gets converted to compressed bit stream.

The location map of the expanded integer wavelet coefficients, changeable bits of all coefficients and a hash value determined by applying SHA-256 cryptographic hash function [13] on the image itself are embedded into the changeable bits of difference numbers in the Integer Wavelet Transform. During the extraction process, after the reversible color conversion and IWT, all the changeable bits are extracted. The changeable bits are divided into three segments. The location map is determined from the first segment, the original changeable bits are determined from the second component and the embedded hash is retrieved from the third component. An image can be reconstructed by replacing the changeable bits with decompressed changeable bits. If a match occurs between the hash code of the extracted hash and hash code of the reconstructed image, the watermark is authentic and original image can be reconstructed. The approach has the disadvantage that it is less accurate for some test images.

C. Invertible Integer to Integer Wavelet Transform

Traditional wavelet transform is not well suited for reversible watermarking because there is no guarantee of the reversibility of the original image. In the traditional approach, the integer type pixels are transformed into floating point values after applying wavelet and scaling function. By embedding watermark on these floating point values leads to loss of information as these floating point transformed values get truncated to integer. With this, the reconstruction of the original image becomes impossible.

A solution to this problem is to use an invertible integer to integer wavelet transform [14] based on lifting which maps integers to integers and it leads to the complete reconstruction of the original image. In this approach, the watermark is embedded into the high frequency wavelet coefficients by using LSB substitution or bit shifting method. In LSB substitution method, the watermark bits are embedded by replacing the LSB of the high frequency coefficients as given in eqn. (1):

$$c^w = 2 \cdot \left\lfloor \frac{c}{2} \right\rfloor + w \qquad (1)$$

Where c, c^w, and w are the original, watermarked wavelet coefficients and the watermark bit respectively. With the p-shifting technique, the original wavelet coefficient is multiplied by 2^p where ‘p’ represents a positive integer and the watermark is embedded into ‘p’ LSBs as:

$$c^w = 2^p \cdot c + w \qquad (2)$$

Where $w = 2^0 \cdot w_0 + 2^1 \cdot w_1 + \cdots + 2^{p-1} \cdot w_{p-1}$ and $\{w_0, w_1, \cdots, w_{p-1}\}$ are a set of ‘p’ watermark bits.

The problem of overflow and underflow arises in this scheme that leads to the inability to recover the original image back. This can be overcome by identifying LSB changeable and bit shiftable image blocks. An image block is LSB changeable if by embedding a watermark using LSB substitution method does not create underflow / overflow problem. An image block is said to be 'p' shiftable block, if by embedding a watermark using bit shifting technique does not create underflow / overflow problem.

In order for the retrieval of the message and for the reconstruction of the original image, a location map is defined that specifies the blocks that are watermarked. The size of the location map is same as the number of blocks. Then, the location map is embedded into the LSB changeable blocks using LSB substitution. The LSB changeable blocks are selected based on a secret key shared with the decoder. The original LSBs replaced while embedding location map are also embedded into the image. The message bits and original LSBs are embedded sequentially.

During the watermark extraction and recovery process, after partitioning the image into blocks, invertible integer wavelet transform is applied. The selection of LSB changeable blocks are made based on the secret key. The location map is retrieved by extracting LSBs of the high frequency coefficients. The blocks in which the watermarking has been done are identified from the location map. Then the message bits and original LSBs are extracted that leads to the reconstruction of the original image.

D. Reversible Contrast Mapping

The scheme uses a Reversible Contrast Mapping (RCM) [15], which is an Integer transform applied on pairs of pixels. A forward RCM transformation is applied on pairs of pixels, which restricts the values to be within 0 and 255 in order to prevent underflow / overflow problem. During embedding, the watermark is embedded on the LSB's of the transformed pixel pairs. Each transformed pixel pairs are correctly identified in order to extract the watermark and for the restoration of the un-watermarked pixels. Bits 1 and 0 in the first pixel of each pair determines whether it is a transformed pair or not respectively. The process includes two phases: Marking and Watermark extraction and original recovery. The marking process includes:

a) Pair-wise partitioning of the pixels of the original image.
b) For each pair (x, y)
   a. If the pixel pair is not composed of odd values and it belongs to the domain, after transforming the pixel pairs by equation (3), set LSB of x' as bit '1' and the LSB of y' is kept for embedding.

$$x' = 2x - y \quad and \quad y' = 2y - x \qquad (3)$$

   b. If the pixel pair is composed of odd values and also belongs to the domain, set LSB of x as bit '0' and LSB of y is used for watermark embedding.
   c. If the pixel pair does not belong to the domain, set the LSB of x as bit '0' and the actual value remains unchanged.
c) Replace identified bits with watermark bits.

The procedure for watermark extraction and recovery of original image is:

a) Pair-wise partitioning of the pixels of the original image
b) For each pair (x', y')
   i) If it is a transformed pair, which is identified from the LSB of the first pixel of each pair, the LSB of y' is extracted and then reset the LSB's of x', y' as bit '0'. The original pair of pixels can be recovered by

$$x = \left\lceil \frac{2}{3}x' + \frac{1}{3}y' \right\rceil \quad and \quad y = \left\lceil \frac{1}{3}x' + \frac{2}{3}y' \right\rceil \qquad (4)$$

   ii) If the LSB of x' is bit '0' and the pixel pair (x', y') with the LSBs set to bit '1' and it belongs to the domain, the LSB of y' is extracted and the original pixel pair is restored by setting the LSB's to bit '1'.
   iii) If the LSB of x' is bit '0' and the pair (x', y') does not belongs to the domain, the LSB of x' is replaced with true value extracted from the watermark sequence in order to recover the original pixel pair (x, y).

The advantages of the scheme are

- ✓ Space for watermark embedding is provided if at least half of the total number of pixel pairs is transformed.
- ✓ RCM is completely invertible even if the LSBs of the transformed pixels are lost.
- ✓ The approach allows robustness against cropping.
- ✓ Low cost and less complex approach.

E. Complementary Predictors and Context Embedding

Most of the reversible watermarking approaches use a single predicted value, whereas this scheme defines two complementary predicted values [16] for each pixel. Classis predictors are used to compute the predicted values. In order to select the error with the minimum absolute value, e_i, the prediction errors are computed as given in eqn. (5).

$$e_a = x_i - \bar{x}_a \quad and \quad e_b = x_i - \bar{x}_b \tag{5}$$

where x_i is the pixel value, $\bar{x}_a, \bar{x}_b$ are the complementary predicted values. The embedding of watermark is decided from the prediction errors. If $e_a, e_b >= 0 \; or \; e_a, e_b < 0$, the watermark is embedded on the current pixel using eqn. (6).

$$x_i' = x_i + \delta_i \tag{6}$$

Where δ_i is the distortion introduced in x_i. If $e_a >= 0, e_b < 0 \; or \; e_a < 0, e_b >= 0$, the embedding on x_j is done by context embedding approach as given in eqn. (7), where x_j is the neighbour of x_i.

$$x_j' = \begin{cases} x_j - \delta_i, & if \; e_i = e_a \\ x_j + \delta_i, & if \; e_i = e_b \end{cases} \tag{7}$$

An overflow map is maintained to solve the underflow / overflow problem. The watermarked value for the current pixel is checked to identify whether underflow / overflow has occurred. If so, the position for x_i is stored in the map and the original pixel values remains unchanged.

In addition to the computation of complementary predictors for each pixel, the authors have extended their work by defining complementary predictors for horizontal pixel pairs. The watermark is embedded on the horizontal pixel pairs depending on the prediction errors, R and L selected for watermarking and the process is given in eqn. (8).

$$x_1' = \begin{cases} x_1 + \delta_1, & if \; e_1 >= R \\ x_1 - \delta_1, & if \; e_1 <= L \end{cases} \quad and \quad x_2' = \begin{cases} x_2 + \delta_2, & if \; e_2 >= R \\ x_2 - \delta_2, & if \; e_2 <= L \end{cases} \tag{8}$$

F. Adaptive Pairing

Instead of using fixed pair-wise pixels for embedding watermark, this approach selects a pair of pixels adaptively [17] based on the similarity in prediction errors. The current pixel gets paired with one of its neighbouring pixels which improve the embedding process by utilizing both pixels in a pair. The selection of the same pixel pairs during embedding and extraction are done by a pixel classification procedure.

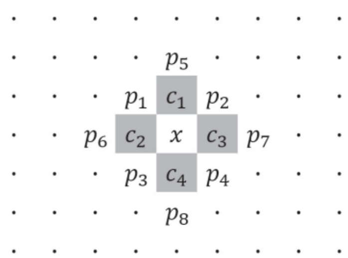

Figure 1. Prediction context (c_1-c_4) and pairing partners (p_1-p_8) for a pixel, x.

The embedding process starts with partitioning the image into two disjoint sets: cross and dot. The watermark is embedded on cross set first, followed by dot set. The prediction context of the pixels in one set is computed from the pixels in the other set. Figure 1 shows the prediction context and all the possible pairing partners for the current pixel, x. The prediction context is used to compute the local complexity of each pixel in the set by using eqn. (9).

$$l_c = (c_1 - c_2)^2 + (c_2 - c_4)^2 + (c_4 - c_3)^2 + (c_3 - c_1)^2 \tag{9}$$

The pixels in each set are sorted in the increasing order of the local complexity and only first ‘k’ pixels are selected for embedding. ‘k’ is a positive integer that controls the embedding rate. The average of the prediction context is used to predict each of the selected pixel ‘x’ in the current set and then ‘x’ is assigned to one of the three groups based on the criteria given below:

$$x \in \begin{cases} A, if\ L < e_x < R \\ B, if\ e_x > R+1\ or\ e_x < L-1 \\ C, if\ e_x \in \{L-1,\ L,\ R,\ R+1\} \end{cases} \qquad (10)$$

where R and L are the threshold values for predicted errors and ‘e_x’ is the prediction error.

The pixels in group ‘A’ are not used for watermarking. The pixels in group ‘B’ are shifted to prevent overlapping with the watermarked pixels from group ‘C’. The pixels in group ‘C’ are paired adaptively and are used for watermarking. The pixels are marked / shifted based on their prediction error. A pixel pair remains unchanged if underflow / overflow occur after marking or shifting the pixels. There are four different cases for a pixel pair (x, p): both of the pixels are marked with $\log_2 3$ bits (*mm*1) or 1 bit (*mm*2), *x* is marked and *p* is shifted (*ms*) or *x* is shifted and *p* is marked (*sm*). The embedding proceeds as given in eqn. (11).

$$(x', p') = \begin{cases} (x,p)+(b_1,b_2), & if\ (e_x,e_p)=(R,R)\ \ (mm_1) \\ (x,p)+(b,b), & if\ (e_x,e_p)=(R+1,R+1)\ \ (mm_2) \\ (x,p)+(b,1), & if\ (e_x,e_p)=(R,R+1)\ \ (ms) \\ (x,p)+(1,b), & if\ (e_x,e_p)=(R+1,R)\ \ (sm) \end{cases} \qquad (11)$$

where $(b_1,b_2) \in \{(0,0),(0,1),(1,0)\} and\ b \in \{0,1\}$

The watermark extraction process is done in the reverse order of the set used for embedding. i.e dot set is processed before cross set. Each pixel is assigned to the same group as done in embedding. The marked and shifted pixels are identified by the same process as done during embedding. Then the watermark bits are extracted and original image is reconstructed.

G. Adaptive pairwise with horizontal grouping

While comparing with adaptive pairing approach, this scheme considers pairing of pixels in the horizontal direction [18]. The approach considers 6 prediction contexts (c_1 to c_6) and two new pixels (p_1, p_2). The processing order remains unchanged; the cross set is embedded before dot set and vice versa for the watermark extraction process. Figure 2 shows the prediction context and all the possible pairing partners for the current pixel, ‘xp’. The main advantage of considering horizontal grouping is that it maintains correlation between horizontal neighbours with a good prediction context.

.	.	.	.	.	.	.
x	x	p7	p5	p8	x	x
.	.	c1	c2	c3	.	.
p11	p3	p1	xp	p2	p4	p12
.	.	c4	c5	c6	.	.
x	x	p9	p6	p10	x	x
.	.	.	.	.	.	.

Figure 2. Prediction context (c_1-c_6) and pairing partners (p_1-p_{12}) for a pixel, xp.

H. Asymmetric Histogram shifting of prediction errors

In this scheme, rather than using single prediction scheme, a multi-prediction scheme is used [19]; where multiple values for the current pixel are predicted. The prediction values of the current pixel ‘x’ are calculated from previously visited pixels.

		x_6	x_7
	x_3	x_2	x_4
x_5	x_1	x	

Figure 3. contexts for prediction for current pixel, ‘x’.

From all the reference pixels of ‘x’, one pixel is selected by applying asymmetric selection function on prediction errors for all these reference pixels as shown in Figure 3. An asymmetric selection function is one that does not obey symmetric distribution.

Examples are maximum() and minimum(). If max $(\cdot)$ is used as the asymmetric selection function, the maximum prediction errors e_{ij}^{+} are calculated by using eqn. (12).

$$e_{ij}^{+} = \max(el_{ij}, eu_{ij}, ed_{ij}) \quad (12)$$

where, el_{ij}, eu_{ij} *and* ed_{ij} are the prediction errors of left, upper and upper left neighbours of current pixel and are calculated as given in eqn. (13).

$$\begin{cases} el_{ij} = x_{ij} - x_{i,j-1} \\ eu_{ij} = x_{ij} - x_{i-1,j} \\ ed_{ij} = x_{ij} - x_{i-1,j-1} \end{cases} \quad (13)$$

An asymmetric error histogram is constructed after calculating all these selected errors, 'e' in the original image. Asymmetric histograms perform better than conventional symmetric histogram in terms of image quality. During the embedding process, in order to solve the underflow / overflow issue, a location map is used, which is created by assigning '0' if the pixel value is 254 and assign '1' if the pixel value is 255. The location map, L is appended to the watermark. The watermark is embedded by using eqn. (14).

$$y_{ij} = \begin{cases} x_{ij} - 1, & if\ Z_{+} < e_{ij}^{+} < P_{+} \\ x_{ij} - w, & if\ e_{ij}^{+} = P_{+} \\ x_{ij}, & otherwise \end{cases} \quad (14)$$

Where, 'w' is the watermark to be embedded, P_{+} represents the peak point and Z_{+} represents its left point of the asymmetric error histogram, $h_{+}(e)$. By applying min $(\cdot)$, $h_{-}(e)$ can be constructed and watermark can be embedded using the following formula:

$$y_{ij} = \begin{cases} x_{ij} + 1, & if\ P_{-} < e_{ij}^{-} < Z_{-} \\ x_{ij} + w, & if\ e_{ij}^{-} = P_{-} \\ x_{ij}, & otherwise \end{cases} \quad (15)$$

The image quality and embedding capacity can be improved by using a combined approach, where both $h_{+}(e)$ and $h_{-}(e)$ are used for embedding watermark. These error histograms are constructed by applying shifting on error histogram in the opposite direction. The embedding process starts with embedding the first watermark, w_1 on $h_{+}(e)$, followed by second watermark w_2 on $h_{-}(e)$.

During the watermark extraction process, the predicted values of the pixel 'Z_{ij}' in the watermarked imageare calculated from reference pixels and later prediction errors are calculated by applying the same asymmetric selection function. The second watermark, w_2 is extracted first by using the eqn (16).

$$w_2 = \begin{cases} 0, & if\ e_{ij}^{-} = P_{-} \\ 1, & if\ e_{ij}^{-} = P_{-} + 1 \end{cases} \quad (16)$$

Thus the restoration of y_{ij} can be done by eqn. (17)

$$y_{ij} = \begin{cases} z_{ij} - 1, & if\ P_{-} < e_{ij}^{-} \leq Z_{-} \\ z_{ij}, & otherwise \end{cases} \quad (17)$$

The first watermark, w_1 is extracted as given in eqn. (18)

$$w_2 = \begin{cases} 0, & if\ e_{ij}^{+} = P_{+} \\ 1, & if\ e_{ij}^{+} = P_{+} - 1 \end{cases} \quad (18)$$

And the pixel value x_{ij} is restored using the equation given below:

$$x_{ij} = \begin{cases} y_{ij} - 1, & if\ Z_{+} \leq e_{ij}^{+} < P_{+} \\ y_{ij}, & otherwise \end{cases} \quad (19)$$

After the extraction of all the watermark bits, w_1 and w_2, the number of pixels with values 1 and 254 are calculated from second row and column. Let it be 'l', collect 'l' bits from the end of w_2. It represents the embedded location map. By doing the reverse process of creating the location map, the original image can be reconstructed.

I. Trigonometric functions

After partitioning the cover image into blocks of size 2×2, each block is interpolated to 3×3 sized blocks by using eqn. (20).

$$C(1,2)=\sqrt{\frac{\{C(1,1)\}^2+\{C(1,3)\}^2}{2}},\ C(2,1)=\sqrt{\frac{\{C(1,1)\}^2+\{C(3,1)\}^2}{2}}$$
$$C(2,2)=\sqrt{\frac{\{C(1,2)\}^2+\{C(3,2)\}^2}{2}},\ C(2,3)=\sqrt{\frac{\{C(1,3)\}^2+\{C(3,3)\}^2}{2}} \quad (20)$$
$$C(3,2)=\sqrt{\frac{\{C(3,1)\}^2+\{C(3,3)\}^2}{2}}$$

Trigonometric functions [20] are applied on the newly created values using eqn. (21)

$$C^{1}(1,2)=C(1,2)+2\cos\frac{\{C(1,1)\}+\{C(1,3)\}}{2}$$
$$C'(2,1)=C(2,1)+2\cos\frac{\{C(1,1)\}+\{C(1,3)\}}{2} \quad (21)$$

Logarithmic values of these new values are found out and are used for selecting bit stream. The decimal values of those selected bit streams are embedded into the new elements. During the extraction process, after partitioning the watermarked image, C'' into 3×3 blocks, the decimal value of the watermark is extracted by the following eqn.

$$w_d = C''-C' \quad (22)$$

Where, C' is the recovered image from cover image and w_d is the decimal value of the watermark. Then the bit stream is recovered using the trigonometric functions.

IV. APPLICATIONS

- **Content Authentication**

  Digital signatures [21] can be used to authenticate the original work of an owner.

- **Image Theft Identification**

  With the advanced technology of modern cameras, it is possible to get the time, date and geographic location of the photo taken. But identifying the person who had taken the photo is a challenging issue. With the embedding of some unique features, for e.g. biometrics, the person who has taken the photo can be identified [22].

- **Medical Applications**

  With the use of reversible watermarking, patient's information can be embedded into the cover image [23]. The recovery of original image is essential to help the doctor for the better diagnosis.

- **Military Applications**

  By embedding confidential information as a watermark into the cover image, security of the watermark is a major concern in military applications.

V. CONCLUSION

In this paper, a detailed review has been made on current literatures on reversible watermarking. Watermarks are very useful mainly for copyright protection and content authentication. With the use of reversible watermarking, not only the watermark but also the original image can be restored. And it is very essential for military and medical applications.

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