Reversible Image Authentication with Tamper Localization Based on Integer Wavelet Transform

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Abstract— In this paper, a new reversible image authentication technique with tamper localization based on watermarking in integer wavelet transform is proposed. If the image authenticity is verified, then the distortion due to embedding the watermark can be completely removed from the watermarked image. If the image is tampered, then the tampering positions can also be localized. Two layers of watermarking are used. The first layer embedded in spatial domain verifies authenticity and the second layer embedded in transform domain provides reversibility. This technique utilizes selective LSB embedding and histogram characteristics of the difference images of the wavelet coefficients and modifies pixel values slightly to embed the watermark. Experimental results demonstrate that the proposed scheme can detect any modifications of the watermarked image.

Keywords: Reversible Watermarking; Authentication; Tamper Localization; Histogram modification;

I. INTRODUCTION

Digital watermarking is the well known approach for image authentication reported in the literature. The traditional digital signature authentication methods have some drawbacks. As the signature is appended to a digital image, it increases the file size and it can also be removed easily. Moreover, it can not be used to locate the tampered area of an image with high accuracy. But, digital watermarking overcomes the above drawbacks.

In digital watermarking, the file size keeps unchanged after embedding the watermark also. Authentication watermark is very sensitive to any modifications imposed upon an image and can be used for tamper localization with high accuracy. In most conventional authentication techniques based on watermarking, the original image is distorted permanently due to the authentication itself. That is, the original image can not be recovered from the marked image when the marked image is deemed authentic. These distortions are not allowed in some sensitive applications, such as law enforcement, medical and military image systems. Thus, it is desired to undo the changes introduced by authentication if the image is verified as authentic. Data embedding techniques satisfying this requirement are referred to as reversible or lossless image authentication techniques. As long as the marked image is authentic, the original image can be reconstructed without any distortion. An effective authentication scheme basically should have the desirable features: tamper detection and localization, good perceptual invisibility, and detection without requiring explicit knowledge of the original image [1].

Many reversible authentication watermarking schemes for images have been reported in the literature [1]–[25], whereas rare of the schemes satisfy all the basic desirable features [2]. Most of the schemes do not provide tamper localization capability, which plays very important role in image authentication. Hierarchical authentication watermark in conjunction with the lossless generalized-LSB data embedding algorithm is used to offer localized lossless authentication watermark [22]-[25]. Hashes of IWT coefficients can also be used as watermark [3]. Some watermarking schemes apply data compression to reduce the size of embedding data [2]. The second category of reversible algorithms uses the difference expansion method to embed the watermark [4]-[9]. Integer Haar wavelet transform is applied to an image and the watermark is embedded into high-frequency coefficients by difference expansion [4]. Alattar extended Tian’s scheme and applied the same difference expansion idea [5]. The third category of algorithms use histogram shifting method to embed the watermark [6]-[12]. In [10], the hash code of the image is combined with a binary logo image by a bit-wise exclusive OR and then embedded in the histogram of the difference image from the original image. Watermark is also embedded in wavelet coefficients in reversible manner [4], [12]-[15]. Lossless embedding of watermark is implemented with DCT coefficients [16]-[19]. Block-based reversible watermarking is implemented in [19].
In this paper, a new reversible authentication technique for images, which verifies the image integrity, identifies tamper detection, localization and reconstruction of original image is proposed. In order to verify the integrity of the image, a binary logo image is replicated to the size of the image and is embedded in selective LSB of the original image. The range of pixel value of the original image at the two extremes is narrow down to avoid underflow/overflow problems. To obtain reversibility, the original values of the modified LSBs and the pixels that are shifted to avoid underflow/overflow problems must also be sent as side information to the receiver as overhead data. IWT is applied on the watermark embedded image. A reversible watermarking technique using histogram modification is applied on the coefficients of high frequency sub-bands to embed the overhead data. Then inverse IWT is applied to get the final watermarked image.

II. INVERTIBLE INTEGER-TO-INTEGER WAVELET TRANSFORMS

A. Advantages of Integer Wavelet Transform

Conventional wavelet transform is not applicable to reversible authentication watermarking scheme since it does not guarantee the reversibility [113,114]. When an image is transformed into a wavelet domain using a conventional wavelet transform, the values of the wavelet coefficients will be the floating-point. If these coefficients are changed during the watermark embedding, the corresponding watermarked image block will not have accurate values. Any truncation of the floating-point values of the pixels may result in loss of information and may ultimately lead to the failure of the reversible authentication watermarking systems, that is, the original image can not be reconstructed from the watermarked image. Information may be lost through forward and inverse transforms. Furthermore, conventional wavelet transform is in practice implemented as a floating-point transform followed by a truncation or rounding since it is impossible to represent transform coefficients in their full accuracy. Hence, information is potentially lost through forward and inverse transforms [113]. To avoid this problem, an invertible integer-to-integer wavelet transform based on lifting is used in the proposed scheme. It maps integers to integers and does not cause any loss of information through forward and inverse transforms.

B. Lifting Scheme Haar Transform

The wavelet Lifting Scheme is a method for decomposing wavelet transforms into a set of stages. Lifting scheme algorithms have the advantage that they do not require temporary arrays in the calculations steps and have fewer computations. When wavelet algorithms are expressed in a lifting scheme structure they are more efficient and they are simpler and easier to understand [115]. The lifting scheme consists of the following three steps:

- **Split step** – It is also called lazy wavelet transform. It divides the input data into odd and even elements.
- **Predict step** – It predicts the odd elements from the even elements.
- **Update step** – It replaces the even elements with an average.

The forward lifting scheme wavelet transform divides the data set being processed into an even half and an odd half. The index of the element in the even half is represented as even, and the index of the element in the odd half is represented as odd. A simple lifting scheme forward transform is depicted in Fig.1.

In the proposed scheme, lifting scheme version of the Haar transform is used. In this transform, the prediction step predicts that the odd element will be equal to the even element. The difference between the predicted value (the even element) and the actual value of the odd element replaces the odd element. For the forward transform iteration $j$ and element $i$, the new odd element, $j + 1, i$ would be

$$odd_{j+1,i} = odd_{j,i} - even_{j,i}$$

(1)

In the lifting scheme version of the Haar transform the update step replaces an even element with the average of the even and odd pair.

$$even_{j+1,i} = \frac{even_{j,i} + odd_{j,i}}{2}$$

(2)

The original value of the odd element has been replaced by the difference between this element and its even predecessor. The original value of $odd_{j,i}$ is recovered by using (3).

$$odd_{j,i} = even_{j,i} + odd_{j+1,i}$$

(3)

Substituting (3) into (2), $even_{j+1,i}$ becomes,

$$even_{j+1,i} = \frac{even_{j,i} + even_{j,i} + odd_{j+1,i}}{2}$$

(4)

The averages (even elements) become the input for the next recursive step of the forward transform which is shown in Fig. 2.
One of the elegant features of the lifting scheme is that the inverse transform is a mirror of the forward transform. In the case of the Haar transform, additions are substituted for subtractions and subtractions for additions. The merge step replaces the split step. Fig. 3 depicts the lifting scheme inverse transform.

The range of pixel value of the original image is narrow down before applying IWT. Let $S$ be shifting threshold, $x$ and $x'$ be pixel value before and after modification. For a 8-bit gray-scale image,

$$x' = x + S, \text{ if } x \in [0,S]$$

$$x' = x - S, \text{ if } x \in [255-S,255]$$

Now the range of pixel value is changed from $[0,255]$ to $[S, 255-S]$. The pixels that are shifted must be recorded (book keeping data) and send to the receiver along with watermark as an overhead data.

B. Watermark Generation

The watermark to be embedded is taken as a logo or a random sequence of predefined bits which is known to both the sender and the receiver. The advantage of using the logo is that cropping can be easily detected.

The watermark is embedded in spatial domain, that is, LSB of selected pixels are modified to embed the watermark. The original image is divided into $m \times m$ sub-blocks (say, $3 \times 3$ or $5 \times 5$). The size of the sub-block defines the localization accuracy. If more accuracy is required, then the sub-block size should be minimum; otherwise, larger sub-blocks can be used. The watermark is generated by replicating the logo image so that the size of the watermark matches with the number of sub-blocks in the original image. Fig. 4 depicts the watermark generation process for lena image ($256 \times 256$). The size of the sub-block is taken as $5 \times 5$ and hence the size of the logo is $51 \times 51$. The original logo and the generated watermark are shown in Fig. 4(b) and Fig. 4(c) respectively. To provide additional level of security, the generated watermark is scrambled using a shared secret key. Fig. 4(d) shows the scrambled watermark.
\[ R_{i,j} = \text{mod} \left( \sum_{a=1}^{m} \sum_{b=1}^{m} C_{a,b}, 2 \right) \]  
\[ \text{inc} = R_{i,j} \oplus W_{i,j} \]  
\[ C_{\text{centre}} = C_{\text{centre}} + \text{inc} \]  
\[ lmap(i,j) = \text{inc} \]  

where \( C_{a,b} \) is the pixel value of the sub-block \( F_{i,j} \), \( R_{i,j} \) is the remainder in dividing the sum of pixel values of the sub-block \( F_{i,j} \) by 2, \( W_{i,j} \) is the watermark bit and \( C_{\text{centre}} \) is the centre pixel of the sub-block \( F_{i,j} \). If the remainder \( R_{i,j} \) and watermark bit \( W_{i,j} \) are same, then \( \text{inc} \) will be zero and hence there is no need to make any changes in the sub-block; Otherwise, the centre bit, \( C_{\text{centre}} \), is incremented by \( \text{inc} \) (one). The result of the embedding process is Layer-1 Watermarked Image.

To obtain reversibility, the original values of the modified LSBs must also be sent as overhead data to the receiver. A ‘1’ in the location map \( (lmap(i,j)) \) identifies the modified LSB. The location map is embedded in wavelet coefficients in reversible manner.

### D. Constructing Overhead Data

After embedding watermark in the LSBs of the image, the overhead data is embedded using reversible watermarking. It consists of book keeping data which provides information about the pixels shifted to avoid underflow/overflow and location map which provides information about the modified LSBs during watermark embedding process. This overhead data is embedded in wavelet domain in a reversible manner. The book keeping data is converted into a single bit stream as follows:

\[ B = S \cup p \cup (r_1 \cup c_1) \cup (r_2 \cup c_2) \ldots \ldots (r_p \cup c_p) \]  

where \( S \) is the shifting threshold and \( p \) is the number of pixels shifted, \( r_k \) and \( c_k \) are the row and column of the \( k^{th} \) pixel shifted. The size of location map is \( M/5 \times N/5 \). It is also represented as a single bit stream \( L \) by reading it in column wise. The overhead data bit stream \( O \) is formed by combining \( B \) and \( L \).

\[ O = B \cup L \]  

The binary bit stream \( O \) can be compressed either using simple method like Run Length Encoding or using JBIG compression algorithm. The entire embedding process if depicted in Fig. 5.

### E. Overhead Data Embedding (Layer -2)

The L-1 watermarked image is decomposed by applying integer haar wavelet transform to get LL, HL, LH and HH sub-bands. The overhead data is embedded in high frequency sub-bands only. Let the size of the sub-bands be \( X \times Y \). Difference images, \( dD(i,j) \), \( dH(i,j) \), \( dV(i,j) \) of size \( X \times Y/2 \) are constructed for HH, HL and LH sub-bands respectively. For \( 1 \leq i \leq X \) and \( 1 \leq j \leq Y/2 \),

\[ dD(i,j) = CD(i,2j) - CD(i,2j-1) \]
\[ dH(i,j) = CH(i,2j) - CH(i,2j-1) \]
\[ dV(i,j) = CV(i,2j) - CV(i,2j-1) \]  

where \( CD(i,j), CH(i,j) \) and \( CV(i,j) \) are the coefficients of HH, HL and LH sub-bands respectively. The odd-line coefficients \( i, 2j-1 \) are subtracted from the even-line coefficients \( i, 2j \) to construct the difference image.

The histogram shifting technique can be applied to make room for embedding overhead data [10-12]. The histogram bins of -2 and 2 are emptied by shifting some coefficient values in the difference images. If the difference value is greater than or equal to 2, then the even-line coefficient in the respective sub-band is incremented by one. If the difference value is less than or equal to -2, then the even-line coefficient in the respective sub-band is decremented by one. Then, the modified difference image is represented as \( dD', dH' \) and \( dV' \).
\[ dD'(i, j) = CD'(i, 2j) - CD'(i, 2j-1) \]
\[ dH'(i, j) = CH'(i, 2j) - CH'(i, 2j-1) \]
\[ dV'(i, j) = CV'(i, 2j) - CV'(i, 2j-1) \]

Where,
\[ CD(i, 2j) = \begin{cases} CD(i, 2j) + 1 & \text{if } dD(i, j) \geq 2 \\ CD(i, 2j) - 1 & \text{if } dD(i, j) \leq -2 \\ CD(i, 2j) & \text{otherwise} \end{cases} \]
\[ CH(i, 2j) = \begin{cases} CH(i, 2j) + 1 & \text{if } dH(i, j) \geq 2 \\ CH(i, 2j) - 1 & \text{if } dH(i, j) \leq -2 \\ CH(i, 2j) & \text{otherwise} \end{cases} \]
\[ CV(i, 2j) = \begin{cases} CV(i, 2j) + 1 & \text{if } dV(i, j) \geq 2 \\ CV(i, 2j) - 1 & \text{if } dV(i, j) \leq -2 \\ CV(i, 2j) & \text{otherwise} \end{cases} \]

After the embedding process is over, inverse IWT is applied to obtain the L-2 Watermarked Image.

**F. Post processing**

The pixel values of the L-2 Watermarked Image are checked for overflow/underflow. If it does, the value of shifting threshold is incremented by one and the entire process is repeated once again; if it doesn’t produce overflow/underflow, the watermarked image is ready to transmit.

**G. Watermark Extraction and Verification**

Fig. 6 depicts the watermark extraction and recovery scheme. At the receiving side, the first step is to extract the overhead data in the watermarked image.

The odd-line fields of the watermarked sub-band coefficients are not affected in the embedding process and is given by,
\[ CD_u(i, 2j-1) = CD'(i, 2j-1) \]
\[ CH_u(i, 2j-1) = CH'(i, 2j-1) \]
\[ CV_u(i, 2j-1) = CV'(i, 2j-1) \]

The coefficients are left unchanged in all other cases.
\[ CD_u(i, 2j) = CD(i, 2j) \]
\[ CH_u(i, 2j) = CH(i, 2j) \]
\[ CV_u(i, 2j) = CV(i, 2j) \]
extracted and the authenticity of the retrieved image is verified. If the image has not been tampered with and if the image is authentic, then the watermarked image is reversed back to its original form using the overhead data retrieved.

H. Extraction of Overhead Data

The difference images of the three high frequency sub-bands are found. The difference images are scanned in the same order as at the sender side. The overhead data is extracted as follows:

\[
O_r(k) = \begin{cases} 
0 & \text{if } dD_w(i, j) = 1 \text{ or } -1 \\
1 & \text{if } dD_w(i, j) = 2 \text{ or } -2 
\end{cases}
\]

\[
O_L(k) = \begin{cases} 
0 & \text{if } dH_w(i, j) = 1 \text{ or } -1 \\
1 & \text{if } dH_w(i, j) = 2 \text{ or } -2 
\end{cases}
\]

\[
O_J(k) = \begin{cases} 
0 & \text{if } dV_w(i, j) = 1 \text{ or } -1 \\
1 & \text{if } dV_w(i, j) = 2 \text{ or } -2 
\end{cases}
\]

where, \(O_r(k)\) is the overhead data retrieved, \(dD_w\), \(dH_w\) and \(dV_w\) are the difference images of HH, HL, LH sub-bands of watermarked image respectively. It is not necessary to scan all the three sub-band coefficients. The size of the overhead data is also sent as a header in the payload. The two components of overhead data are separated as book keeping data and location map.

All the three difference images are scanned once again to recover the histogram shifting carried out during embedding process. Since only the even-line coefficients are manipulated, the odd-line coefficients of recovered image are directly obtained from the watermarked coefficients as follows:

\[
C_{D}(i, 2j-1) = C_{D}(i, 2j-1)
\]

\[
C_{H}(i, 2j-1) = C_{H}(i, 2j-1)
\]

\[
C_{V}(i, 2j-1) = C_{V}(i, 2j-1)
\]

Where \(C_{D}\), \(C_{H}\) and \(C_{V}\) are the coefficients of HH, HL, LH sub-bands of watermarked image and \(C_{D}\), \(C_{H}\) and \(C_{V}\) are the coefficients of HH, HL, LH sub-bands of recovered image. The even-line coefficients of the recovered image can be expressed as,

\[
C_{D}(i, 2j) = \begin{cases} 
C_{D}(i, 2j) - 1 & \text{if } dD_w(i, j) \geq 2 \\
C_{D}(i, 2j) + 1 & \text{if } dD_w(i, j) \leq -2 \\
C_{D}(i, 2j) & \text{otherwise} 
\end{cases}
\]

\[
C_{H}(i, 2j) = \begin{cases} 
C_{H}(i, 2j) - 1 & \text{if } dH_w(i, j) \geq 2 \\
C_{H}(i, 2j) + 1 & \text{if } dH_w(i, j) \leq -2 \\
C_{H}(i, 2j) & \text{otherwise} 
\end{cases}
\]

\[
C_{V}(i, 2j) = \begin{cases} 
C_{V}(i, 2j) - 1 & \text{if } dV_w(i, j) \geq 2 \\
C_{V}(i, 2j) + 1 & \text{if } dV_w(i, j) \leq -2 \\
C_{V}(i, 2j) & \text{otherwise} 
\end{cases}
\]

The inverse IWT is applied after the coefficients of recovered image are constructed. It is clear that, the resultant image is the L-1 Watermarked Image which contains only the watermark and the distortions due to overhead data embedding are removed. The next step is to verify the authenticity of the image.

I. Image Authentication

Since the watermark is embedded in LSBs of the centre pixel of 5 × 5 sub-blocks, it can be retrieved easily. The watermark bit embedded is retrieved as follows:

\[
R_{i, j} = \text{mod} \left( \sum_{x=0}^{n} \sum_{y=0}^{n} C'_{x,y} \times 2 \right) \quad (21)
\]

\[
W_{i, j} = R_{i, j} \quad (22)
\]

where \(C'_{x,y}\) is the pixel value of the sub-block \(F'_{i,j}\), \(R_{i, j}\) is the remainder in dividing the sum of pixel values of the sub-block \(F'_{i,j}\) by 2, \(W_{i, j}\) is the watermark bit retrieved. The retrieved watermark is inverse permuted using the same secret key used at the sender side. The retrieved watermark is compared with the original watermark. If there are no distortions in the retrieved watermark, then the authenticity is verified; otherwise, it is concluded that the image might has been altered during transmission. Once the image authenticity is verified, the next step is to remove the distortions of watermark embedding and hence the recovery of the original image. If image authenticity is not verified, there is no need of recovery of original image; instead tamper localization is performed to identify the tamper positions.

J. Recovery of Original image

The overhead data retrieved at the earlier stage is used for recovering the original image. Location map provides information about the modified LSBs during watermark embedding process. A ‘1’ in the location map \((\text{map}(i,j))\) identifies the modified LSB. It is used to recover the original values of LSBs. Bookkeeping data provides information about the pixels that are shifted to avoid underflow/overflow condition. The bookkeeping data is in a single bit stream format which is preceded by shifting threshold \(S\) and the number of pixels modified. Consecutive 16-bits are taken at a time in which the first 8-bits identify the row and the next 8-bits identify the column of the pixel shifted (for a 8-bit gray scale image).

Let \(S\) be shifting threshold, \(x\) and \(y\) be the pixel values of watermarked and the recovered original image. For a 8-bit gray-scale image,

\[
x = x' - S, \text{if } x \in [0,S] \quad (23)
\]

\[
x = x' + S, \text{if } x \in [255-S, 255] \quad (24)
\]

Now the range of pixel value is changed from \([S, 255-S]\) to \([0,255]\) and hence the original image is successfully recovered without any distortions.
K. Tamper Localization

If authentication test is failed, it is clear that the watermarked image has been modified and tamper localization is applied to identify the tampering positions. Watermark is generated by replicating the watermark logo and permuted order is generated using the same shuffling key used at the sender side. It is compared with the watermark retrieved. If there is no match, then the respective $5 \times 5$ sub-block in the watermarked image is assumed to be modified. The following example illustrates the tamper localization clearly. Fig. 7(a) and 7(b) are the watermarked image and modified watermarked image respectively. The retrieved watermark is shown in Fig. 7(c). It contains salt and pepper noise from which it is certain that the image has been tampered during transmission. The noise is extracted from the retrieved watermark and inverse shuffling is applied to locate the tamper positions in the original image. In Fig. 7(d), the white blocks depict the tamper positions. Table 1 lists the results of various images using the proposed scheme.

![Figure 7. Tamper Localization](image)

| Image  | Image Size in bits | PSNR in db | MSE   |
|--------|-------------------|------------|-------|
| Lena   | $256 \times 256$  | 51.4143    | 0.6852|
| Baboon | $116 \times 116$  | 49.5756    | 0.8468|
| Peppers| $136 \times 137$  | 50.3320    | 0.7761|
| Barbara| $130 \times 130$  | 50.4714    | 0.7638|
| Camera | $256 \times 256$  | 51.3475    | 0.6905|
| Angel  | $98 \times 130$   | 51.9675    | 0.6429|
| Bridge | $131 \times 90$   | 50.4271    | 0.7677|
| Dragon | $135 \times 101$  | 52.2837    | 0.6199|

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