Robust copyright protection using multiple ownership watermarks

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Abstract: Generally, conventional transform (DWT and DFT, etc.)-based watermarking techniques provide only one spectrum plane for embedding the watermark, thus the embedding watermark information can be easily removed. To solve this problem, we propose an efficient cellular automata (CA) based watermarking method that CA transform (CAT) with various gateway values can provide many transform planes for watermark embedding according to various CA rules. In this paper, multiple ownership watermarks are first recorded in the form of an elemental image array (EIA), simultaneously, and then the recorded EIA as the watermark data is embedded into the CAT coefficient. An additional advantage of this proposed method is that EIA is composed of many elemental images and each elemental image has its own property of watermarks. Even though most data of elemental images are lost, the watermarks can be reconstructed from the remaining elemental images successfully. Experimental results show that the proposed technique provides good image quality and is robust in varying degree to some image processing attacks.

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References and links

Recently, security of multimedia data is receiving more and more attention due to the widespread transmission over various communication networks [1-3]. Watermarking techniques play very important role in multimedia copyright protection. Applications that convey ownership information are often desired by organizations that own the copyrights to digital media objects and license them. Watermarking for images is one way to embed the secret information, or a logo, into the original image [4]. Most recently, in order to find the applications for joint ownership, multiple ownership watermarks are used to address single ownership. Here, the question arises. How should multiple watermarks best be embedded? In practice, the researchers expect that embedding them simultaneously is desired [5].

Typical watermarking schemes are based on transform-domain methods and spatial-domain methods [6-8]. However, watermarking based on transform domain is mostly encountered in literature. Transform-domain watermarking schemes, also called multiplicative watermarks, are generally considered to be robust against attacks [9,10]. One major disadvantage of these schemes is that conventional transform-domain techniques provide only one spectrum plane for watermark embedding. When the attacks dissolve the relationships...

1. Introduction

Recently, security of multimedia data is receiving more and more attention due to the widespread transmission over various communication networks [1-3]. Watermarking techniques play very important role in multimedia copyright protection. Applications that convey ownership information are often desired by organizations that own the copyrights to digital media objects and license them. Watermarking for images is one way to embed the secret information, or a logo, into the original image [4]. Most recently, in order to find the applications for joint ownership, multiple ownership watermarks are used to address single ownership. Here, the question arises. How should multiple watermarks best be embedded? In practice, the researchers expect that embedding them simultaneously is desired [5].

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between the original multimedia and the pre-determined set for the watermarking embedding, the watermark data can be removed easily and the watermarking capability for copyright no longer exist.

Integral imaging (II), which was first presented by Lippmann in 1908, has been studied actively as a promising method for next-generation three-dimensional (3D) display [11-14]. In the integral imaging system, a 3D object with full parallax and continuous viewing points can be picked-up and reconstructed. Generally, the pickup part of II is composed of a lenslet array and a two-dimensional (2D) image sensor. Then rays coming from the 3D object are picked-up as an elemental images, each of elemental images has their own perspective of a 3D object, by a 2D image sensor. On the other hand, the reconstruction part of II is a reverse of the pickup process, which has two kinds of integral imaging reconstruction methods. One is based on optical integral imaging reconstruction (OIIR) [15,16] and the other is based on computer integral imaging reconstruction (CIIR) [17-24]. However, the OIIR produces low-resolution due to the limitations of physical devices.

To overcome these drawbacks, the computer-generated integral imaging (CGII) method has been proposed, in which the input images can be computationally recorded and reconstructed by a virtual pinhole array via the principle of geometrical optics [25]. CGII technique has an additional advantage of being introduced to deal with 2D image. In recent years, the CGII technique becomes an interest topic in the field of image watermarking and encryption. Using this technique, we can record multiple watermarks, simultaneously, in the form of an elemental image array (EIA). The recorded EIA is used as the watermark data for embedding. Meanwhile, multiple watermarks can be reconstructed from the extracted EIA by using the CIIR technique.

In this paper, we discuss a transform-domain watermarking scheme that achieves multiple ownership watermarks embedding. The scheme is based on cellular automata transform (CAT) [25-29] that can provide many spectrum planes for embedding. Meanwhile, by utilizing CGII technique, the multiple watermarks can be recorded as an EIA and be embedded into the cover image, so that embedding multiple watermarks into a cover image simultaneously is achieved. On the other hand, the property of data redundancy of EIA can greatly improve the watermark robustness when the watermarked image against attacking. This method is capable of achieving high robustness, security, and feasibility for embedding multiple watermarks simultaneously.

2. Theoretical analysis

2.1 Multiple watermarks pickup algorithm

To overcome the drawback of low-resolution in the optical-based integral imaging system, the CGII has been presented, in which the input images can be computationally recorded and reconstructed by a virtual pinhole array via the principle of geometrical optics. In the pickup process of the CGII technique, considering a pickup procedure of the (i, j)th elemental image from a watermark image O, the elemental image \( E_{ij}(x, y) \) can be calculated by

\[
E_{ij}(x, y) = O(-\frac{xg}{zk} + i\rho, -\frac{yg}{zk} + j\rho)
\]

where \( x \) and \( y \) represent the coordinates of the \((i, j)\)th pinhole, \( \rho \) is the pitch of a pinhole, \( zk \) denotes the distance between a pinhole array and a input watermark plane image, and \( g \) is usually a fixed distance between the pickup device and the pinhole array.

Figure 1(a) dynamically describes the pickup process of the CGII algorithm. Multiple watermarks are located at the distances of \( z_1 \), \( z_2 \) and \( z_3 \), respectively. The virtual pinhole array is located at the distance of \( z = 0 \). The EIA is recorded at the distance of \( z = -g \).

In the multiple watermarks reconstruction process, the elemental images are directly projected through a computer synthesizes virtual pinhole array to reconstruct the multiple
watermarks by pixel superposition, according to the geometric optics. As shown in Fig. 1(b), the multiple watermarks can be clearly reconstructed at the distance of \( z_1, z_2 \) and \( z_3 \), respectively, along the output plane. Figure 1(c) shows the one dimensional (1D) case of CIIR algorithm. Each of the elemental images are inversely projected on the output plane according to the magnification factor of \( \sigma = \frac{z_k}{g} \).

Fig. 1. Principle of the multiple watermarks pickup and reconstruction: (a) pickup process, (b) reconstruction process.

The elemental images are magnified with a magnification factor \( \sigma = \frac{z_k}{g} \). The reconstructed watermark \( R_k(x, y) \) locates at the distance \( z_k \) can be written as following:

\[
R_k(x, y) = \sum_{i=0}^{M-1-N-1} \sum_{j=0}^{E} E_{ij} \left( -\frac{z_k}{g} + i\rho, -\frac{z_k}{g} + j\rho \right)
\]  

where \( M \times N \) represents the number of elemental images.

Multiple watermarks are pre-processed by CGH, which can provide high robustness due to the property of data redundancy of 2D EIA. Figure 2 shows an example that the plane image reconstruction process against data loss attack and nearly 25% pixels of the elemental images are lost. From the simulation results, we can see that the image can be reconstructed successfully, even though the elemental images were damaged. The reason is that the recorded EIA has many elemental images and each elemental image nearly has full property of the image. Although, most data of the EIA is lost, the image can be reconstructed from the remaining elemental images.
2.2 Cellular automata transform (CAT) and singular value decomposition (SVD)

Cellular automata (CA) are discrete, computational systems that have proved available both as general models of complexity and as more specific representations of non-linear dynamics in the scientific fields [25-29]. Using CAT with various CA bases and rule numbers, it is possible obtain many transform planes for embedding watermarks. CAT can provide many transform planes for secret data embedding according to various CA rules. In general, for a \( K \)-state \( N \)-site CA, there are \( K^N \) rules. There are \( 2^2 \) rules for the two-state and three-site CA. Meanwhile, CA provides difficulty to attacker to detect the embedding position due to the complexity of cellular automata. Consider a \( K \)-state \( N \)-site with the \( m = 2p-1 \) points per neighbourhood cellular automaton, we can define the rule of evolution of cellular automaton by using a vector of integers \( \mathbf{R}_j \) \( (j=0,1,2,\ldots,2^m) \) as following:

\[
a_{(p(j+1))} = \left( \sum_{j=0}^{2^{n-2}} R_j a_j + R_{2^{n-1}} \right) \mod K
\]

where \( R_j \) and \( a_j \) are composed of the permutations of the state of the cells in the neighbourhood. In this scheme, we only considered a simple and commonly used cellular automata model: a 2-state and 3-site CA. If the states of cells are \( a_{0k}, a_{1k}, a_{2k} \) at time \( t \), Eq. (3) can be rewritten as

\[
a_{(t+1)} = (R_0 a_{00} + R_1 a_{10} + R_2 a_{20} + R_3 a_{01} a_{11} + R_4 a_{10} a_{21} + R_5 a_{20} a_{01} + R_6 a_{00} a_{11} a_{21} + R_7) \mod(2)
\]

Here, each set of \( R_j \) can be derived from a given CA rule evolution. To convert a CA rule with the binary representation \((x_0 x_1 x_2 x_3 x_4 x_5 x_6 x_0)\) to the set \((R_0, R_1, R_2, \ldots, R_7)\), the following relationships can be used:

\[
\begin{align*}
R_7 &= x_0; \\
R_6 &= x_1 - R_7; \\
R_5 &= x_2 - R_7; \\
R_4 &= x_3 - R_5 - R_6 - R_7; \\
R_3 &= x_4 - R_7; \\
R_2 &= x_5 - R_3 - R_6 - R_7; \\
R_1 &= x_6 - R_4 - R_5 - R_7; \\
R_0 &= x_7 - R_1 - R_3 - R_4 - R_5 - R_6 - R_7;
\end{align*}
\]

One-dimensional cellular space offers the simplest environment for generating CAT bases. In a 1D space our goal is to generate the transform basis function. CAT basis function \( \xi_{ik} \) can be derived from the following equations:
\[ \xi_{ik} = \alpha + \beta a_{ik} \] \hspace{1cm} (6)

Or
\[ \xi_{ik} = \alpha + \beta a_{ik} a_{ki} \] \hspace{1cm} (7)

where \( \alpha \) and \( \beta \) are the constants.

The 2D CAT bases \( \xi_{ijkl} \) are derived from the 1D CA bases types according to the following equation:
\[ \xi_{ijkl} = \xi_{ik} \xi_{jl} \] \hspace{1cm} (8)

We give an image data \( f_{ij} \), all the CAT techniques seek to present the data in the form:
\[ f_{ij} = \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} \sigma_{kl} \xi_{ijkl} \] \hspace{1cm} (9)

in which \( \sigma_{kl} \) are CAT coefficients, while \( \xi_{ijkl} \) are the transform bases. The basic strategy for image watermarking using CAT as following:

1) Start with a set of CA gateway keys that produce the basic functions \( \xi_{ijkl} \). Fig. 5(a) shows a graphical view of the basic functions generated using a set of the gateway values (CA rule: \( R = 43 \); number of cells in one lattice: \( N = 8 \); basis function type: \( \xi_{ik} = 2a_{ik} a_{ki} - 1 \). Here, we give \( \alpha = -1 \) and \( \beta = 2 \); boundary configuration: cyclic).

2) Calculate the transform coefficients \( \sigma_{kl} \) according to the inverse calculation of Eq. (10).
\[ \sigma_{kl} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} f_{ij} \xi_{ijkl} \] \hspace{1cm} (10)

where \( \xi_{ijkl} \) denotes the inverse of transform bases \( \xi_{ijkl} \).

3) Decompose CAT coefficients \( \sigma_{kl} \) into four distinct classes as shown in Fig. 5(b): those at even \( k \) and \( l \) locations (class I) denotes ‘low frequency’ which contains important information of image. In the subsequent resolution levels, ‘class I’ can be decomposed again into further hierarchical subbands. The process can be repeated until the final resolution level is reached. The remaining (class II: \( k \) even, \( l \) odd; class III: \( k \) odd, \( l \) even; class IV: \( k \) odd, \( l \) odd) of the coefficients are ‘high frequency’ which represent edges and textures of an image. Figure 5(b) shows the level-1 CAT coefficient of the test image ‘Malian flower’.

The singular value decomposition (SVD) [30-33] algorithm is factorizations of a real or complex with several applications in image compression, recognition, watermarking, and other signal processing fields. In respect of image processing, an image can be viewed as a matrix \( A \) with nonnegative scalar entries, can be expressed as
\[ A = U S V^T = \sum_{i=1}^{r} s_i U_i V_i^T \] \hspace{1cm} (11)

where \( U \) and \( V \) are orthogonal matrices, \( S \) is a matrix with the diagonal elements \( s_i \) representing the singular values of \( A \), \( r \) is the rank of the matrix \( A \).

A common method is to apply SVD to the whole image, however, many researches confirm that this method with a poor watermark imperceptibility. In this paper, we propose a watermarking method by the combined use of the CAT and SVD, as the CAT has excellent spatial-frequency localization properties, it quite suitable to identify watermark can be imperceptibly embedded areas in the image. Image watermarking based on SVD has a unique
advantage is that singular values in a digital image are less affected if some image processing is performed because bigger singular values not only preserve most energy of an image but also resist against attacks.

2.3 Multiple watermarks embedding and extracting

![Diagram of the proposed watermark embedding process](image)

The block diagram of proposed watermarking algorithm for embedding the multiple ownership watermarks is shown in Fig. 3, and the details are recorded in Tables 1 and 2.

**Table 1. The multiple watermarks embedding process.**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
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<tbody>
<tr>
<td>1.</td>
<td>Record multiple watermarks in the form of a 2D EIA by using the CGII technique.</td>
</tr>
<tr>
<td>2.</td>
<td>Scramble the elemental images by using the FT algorithm according to the following equation:</td>
</tr>
</tbody>
</table>
|      | \[
|      | \begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 0 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \pmod{N} \] |
|      | where \( x \) and \( y \) represent the pixels values of the original EIA. |
| 3.   | Decompose the cover image by utilizing 2D CAT algorithm with one set of gateway values according to the Eq. 10. |
| 4.   | Select the cover image coefficients \( \sigma_p^q \), where \( p = 1, q = \{ \text{class I: LL} \} \) for watermark embedding. |
| 5.   | Apply SVD to \( \sigma_p^q \): \( \sigma_p^q = U_\sigma S_\alpha T_\sigma^T \). |
| 6.   | Compute the SVD of the scrambled EIA: \( W = U_\sigma S_\alpha (V_\alpha)^T \). |
| 7.   | Modify singular values of the coefficient ‘Class I’ of the host image with the singular values of the watermark (scrambled EIA) as: |
|      | \( \tilde{\sigma}_p^q = U_\sigma (\alpha S_\alpha) V_\alpha^T \), where, \( \alpha \) is embedding parameter. |
| 8.   | Apply the inverse-CAT to the modified CAT coefficient to produce the watermarked image. |

\*The Fibonacci sequence is named after Fibonacci. The sequence 0, 1, 1, 2, 3, 5, 8, 13, ..., and each subsequent number is the sum of the previous two. Fibonacci transform is chaotic in the unit square. It scrambles digital image by using an equation, and the equation is presented in step 2. |

The watermark extraction is the inverse procedure of the watermark embedding and depicted in Table 2. The corresponding details are mainly represented as following:
Table 2. The multiple-watermark extraction process

| Input: Watermarked image with the size of $M \times M$; one set of the gateways of CAT (8-bit CA, Wolfram rule 43, initial input value (01111110)); input parameters for CIIR; |
| Output: Multiple watermarks. |

1. Apply CAT to decompose the watermarked image and the coefficient $\hat{\sigma}_p^q$ is obtained.
2. Use SVD to the obtained coefficient $\hat{\sigma}_p^q$:
   $$\hat{\sigma}_p^q = \hat{U}_p \hat{S}_p \hat{V}_p$$
3. Extract the watermark data from the CAT coefficient.
   $$\hat{S}_\sigma = \hat{S}_\sigma / \alpha$$
4. Reconstruct the watermark data from the CAT subband:
   $$\hat{W} = U_{\gamma_{\sigma}} \hat{S}_\sigma (V_{\sigma})^T$$
5. Apply the inverse-FT to the extracted watermark data and the EIA is obtained.
6. Reconstruct the multiple watermarks from the obtained EIA by utilizing the CIIR technique.

3. Performance evaluation

To show the effectiveness of the proposed watermarking method, we have performed a series of experiments. The computer pickup structure is shown in Fig. 1(a). A virtual pinhole array is utilized in this experiment that is composed of $16 \times 16$ pinholes, the interval between each pinhole is 1.08 mm and the gap $g$ between the EIA plane and the pinhole array is 3 mm. The gray images ‘Malan flower’ and ‘Baboon’ (Figs. 4(a) and 4(b)) with the size of $512 \times 512$ are used as the test host images. In this experiment, three independent 2D images with the same size of $256 \times 256$ are used to represent the multiple ownership watermarks as shown in Fig. 1(a). The pickup distances between the watermarks and the pinhole array are 9, 18 and 30 mm, respectively. The corresponding recorded 2D EIA from the multiple watermarks is shown in Fig. 5(d).

Figures 4(a) and 4(b) show the test images ‘Malan flower’ and ‘Baboon’. Figures 4(c) and 4(d) show the watermarked images based on the proposed method.

Fig. 4. (a) and (b) original images ‘Malan flower’ and ‘Baboon’, (c) and (d) watermarked images based on the proposed method.

To evaluate the quality of the watermarked image after embedding EIA data into the test image, the peak signal-to-noise ratio (PSNR) is introduced in this experiment. The quality of the watermarked image is evaluated by PSNR in dB given by

$$\text{PSNR}(O,O') = 10 \log_{10} \left( \frac{255^2}{\text{MSE}(O,O')} \right) \tag{12}$$

and
\[ \text{MSE}(O,O') = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [O(x,y) - O'(x,y)]^2 \]  \tag{13}

where \( O \) and \( O' \) denote the original and watermarked image, respectively. \( M \times N \) is the size of the original image.

Basically, the larger the PSNR value, the better the quality of the watermarked image is. The PSNR values of Figs. 4(c) and 4(d) are 38.3349 and 37.9327 dB, respectively. The presented results provide a high PSNR values. Meanwhile, by visually, we cannot distinguish the difference between the original images and the watermarked ones.

Figure 5(a) shows the 2D CAT basis function (8 × 8 × 64 cells) with a set of gateway values: Wolfram rule = 43, initial values (01111110), etc. Figure 5(b) displays the coefficients of CAT (four classes). Figure 5(c) shows the energy distribution of the four classes of CAT coefficient. From the result represented from Fig. 5(c), it is clear that the energy of CAT coefficients where located at LL domain (class I) is higher than other three domains. Therefore, the watermark data is embedded into LL domain that can greatly improve the robustness of watermarks. Figure 5(d) shows the EIA recorded from multiple watermarks by using CGII. Figure 5(e) shows the scrambled watermark by using the FT algorithm to the recorded EIA. Figure 5(f) displays the extracted EIA from the watermarked image ‘Malan flower’ and Figs. 5(g)-(i) shows the reconstructed multiple watermarks that located at the display distances of \( z_1 = 30 \), \( z_2 = 18 \) and \( z_3 = 9 \) mm, respectively. From the simulation results, we can see that the proposed method provides good imperceptivity and the watermarks can be clearly reconstructed in their respective pickup positions.

\[
\begin{align*}
\text{(a)} & \quad \text{2D basis functions } A_{ijkl} (8 \times 8 \times 64 \text{ cells}); \quad A_{ijkl} \text{ is the block at the extreme upper left corner. The top row represents } 0 \leq j < 8, \quad i = 0. \\
\text{(b)} & \quad \text{level-1 CAT coefficient of the test image ‘Malan flower’; (c) energy distribution of four classes of CAT coefficient; (d) recoded EIA from the multiple watermarks; (e) scrambled watermark; (f) extracted EIA from the watermarked image ‘Malan flower’; (g)-(i) reconstructed multiple watermarks by using the CII technique.}
\end{align*}
\]

Statistical analysis has been performed on the security of the multiple watermarks. Figures 6(a)-6(c) show the autocorrelation of the three plane images. Figures 6(d) and 6(e) show the autocorrelation of the original 2D EIA and the scrambled 2D EIA. Figure 6 shows that there is a strong self-correlation for the original multiple watermarks and the EIA. However, Figure 6(e) shows that the correlation of EIA after scrambling is much weakness than that of the EIA.
before scrambling. Thus, the EIA after scrambling offers excellent decorrelation capability to resist statistical attack.

Fig. 6. Statistical analysis: (a)-(c) autocorrelation of the multiple watermarks, (d) autocorrelation of the picked-up EIA, (e) autocorrelation of the scrambled EIA.

To check the robustness of the proposed technique, some typical image processing attacks, such as speckle noise, sharpening, blur noise, salt & pepper, Gaussian noise, median filter, occlusion, and JPEG compression are performed on the watermarked images.

Figure 7 (a) shows the reconstructed multiple watermarks under the speckle noise with variance 0.6. Figure 7 (b) shows the reconstructed multiple watermarks against sharpening attack with alpha 0.5. Figures 7 (c) and 7 (d) show the reconstructed multiple watermarks against blur noise and salt & pepper noise attacks, respectively.

Fig. 7. Proposed extracted multiple watermarks against attacks: (a) speckle (variance: \( V = 0.6 \)), (b) sharpening (alpha: \( \alpha = 0.5 \)), (c) blur noise (radius \( R = 2 \)) (d) salt & pepper (density: \( D = 0.5 \)).

Figure 8(a) shows the reconstructed multiple watermarks under Gaussian noise attack with the zero mean and the variance of 0.5. Figure 8(b) shows the reconstructed multiple watermarks against median filter attack. Figure 8(c) shows the reconstructed multiple watermarks against occlusion attack and 30% pixels of the encrypted image are occluded.
Figure 8(d) shows the reconstructed multiple watermarks against JPEG compression attack and the compression factor is given by 0.3.

The proposed multiple-watermark copyright protection method provides a high robustness due to the property of data redundancy of the 2D EIA. To further demonstrate the effectiveness of the proposed algorithm, we comparatively analyze the robustness between the proposed method and the conventional method. In the conventional multiple watermarking method, the multiple watermarks are embedded into the different transform domains. Figure 9 shows the simulation results based on a conventional method, in which the multiple watermarks are embedded into low frequency (class I) and high frequency (classes II and III), respectively.

From the results presented in Figs. 7-9, it is confirmed that our proposed multiple watermarking method provides high robustness in varying degree to some image processing attacks. The conventional multiple watermarking methods can provide considerable robustness when the attack factors are small. However, the robustness of the extracted watermarks will dramatically degrade with the increase of the attack factors.

These experimental results emphasize the fact that elemental images have redundant and distribute memory characteristics, thus the extracted watermarks can robustly be reconstructed from the attacked watermarked images (i.e., some pixels of the watermarked image are lost or destroyed).
4. Conclusion

In this paper, a method for multiple ownership copyright protection based on computer-generated elemental image array (EIA) and its embedding by using cellular automata transform (CAT) has been discussed. The main novelty of this watermarking algorithm resides in the fact that CAT with various rules can provide many transform planes for watermark embedding. However, the conventional watermarking schemes do not possess this attribute. Further, EIA is used for image watermarking that greatly improves the robustness of the multiple watermarks owing to its property. We also tested the robustness of this proposed method against various attacks. The simulation results have confirmed the feasibility and robustness of our proposed method under practical conditions.

The CGII algorithm is used in multiple ownership copyright protection provides many benefits (i.e., it improves the robustness of watermarks. It converts multiple watermarks into a watermark, thus reduces the embedding complexity, etc.) but this method exists noise interference in the watermark reconstruction process. In the future, we will study an effective noise-removed approach to improve this problem.