A Forensic Marking Algorithm based on DWT-SVD using Hologram

Li De
CPRI at Sangmyung
University, Korea
Dept. of Computer at
Yanbian University, China
lide@smu.ac.kr

Jihah Nah
Dept. of Electrical &
Electronic Eng. at Yonsei
University, Korea
jhna@yonsei.ac.kr

JongWeon Kim
Dept. of Copyright
Protection at Sangmyung
University, Korea
jwkim@smu.ac.kr

Abstract

In this paper, a new forensic watermarking algorithm which generates digital hologram from forensic mark and embeds it into DWT-SVD domain was suggested. Forensic watermarking is used to trace the illegal distribution. For the purpose of the high capacity, off-axis hologram is generated from forensic mark and the hologram is embedded into subband of the DWT domain, so that we could reduce the signal interference. Also, we improved the algorithm safety and detection performance by using SVD for the signal embedded hologram.

As a result, we were able to embed 128bits forensic mark for each step and totally 384bits can be embedded and trace the 3 distribution steps.

1. Introduction

As spread the high speed network and illegal distribution of the digital content, the copyright protection takes its rise in a controversial issue. Recently, content service providers have started to remove the digital rights management (DRM) system from music service. So, the DRM free service is a main stream of the digital content industry and the watermarking technology is concerned the alternative technology instead of the DRM.

The watermarking technology can trace the distribution path of the illegal contents which are distributed widely among versatile networks. Many research group including R. Karkarala and A. Sverdlov[1-5] have suggested watermark embedding algorithms in the discrete wavelet transform (DWT) or singular value decomposition (SVD) domain. However these algorithms focused on the robustness about geometrical attacks and compression not multi step tracing of the illegal distribution. Nobukatsu[6] used the optical holography technology as a watermark embedding method. The hologram is generated from the watermark information and it is embedded into the original image after Fourier transform of the hologram. Especially, Kim et al. [7] suggested a blind watermarking algorithm which is used off-axis hologram and has high capacity and robustness against to the geometrical attack.

For the purpose of the tracing of the multiple distributions, the technology has to be able to embed multiple watermarks at each distribution step and detect the information exactly. Even though multiple embedding and detecting using correlation method are possible in the DWT and SVD domain, the payload is not enough. In this case we can extend the payload by reducing the random sequence length, but the detection performance and the geometrical robustness would be inferior.

In this paper, we extended the payload using off-axis hologram, so that the algorithm can embed and detect the multiple watermarks because the hologram was embedded into DWT domain. This also improved the detection performance by using SVD to the signal which is embedded the hologram.

The proposed algorithm is robust to the compression and the geometrical modification because it used the DWT-SVD domain and the characteristic of the hologram. This also can use the bio information and 2D barcode regarding the copyright information or buyer’s information as the forensic mark.

2. Holographic Watermark

In 1948, D. Gabor proposed a novel lensless imaging process, which we know as holography[8]. Leith and Upatnieks suggested offset-reference hologram that solved twin image problem of Gabor’s hologram[9].
Recording and reconstruction of the hologram is shown in Figure 1. As shown in the Figure1, the reference wave from a reference point is collimated by the Fourier lens and strikes the object wave from an object point. These two waves are superposed on recording medium and then recorded on intensity pattern of the resultant field, which is called hologram. The hologram is added to object point’s intensity pattern since each object point construct independent intensity pattern by above process. We used one object point like one bit data which number and coordinate effects energy level of embedding hologram pattern in this paper. The procedure of reconstruction from the hologram is shown in Figure 1(b). We can recover embedding bit data using the Fourier transform of the product of the hologram and reference wave.

![Figure 1](image_url)

**Figure 1.** Recording and reconstruction of the hologram (a) Recording, (b) Reconstruction

Eq. (1) is the Fourier hologram using the reference wave and the object wave.

\[
U_R(\xi, \eta) = |O(\xi, \eta)|^2 + |R(\xi, \eta)|^2 + O(\xi, \eta)^* R(\xi, \eta) \exp\{-j \frac{2\pi}{\lambda_1 f} (\xi x_r + \eta y_r)\} + j \frac{2\pi}{\lambda_1 f} (\xi x_0 + \eta y_0)\} + O(\xi, \eta)^* R(\xi, \eta) \exp\{+j \frac{2\pi}{\lambda_1 f} (\xi x_r + \eta y_r)\} - j \frac{2\pi}{\lambda_1 f} (\xi x_0 + \eta y_0)\} \tag{1}
\]

We will use third term and fourth term because the first term and second term just describe the intensities of the reference wave and the object wave. Eq. (2) is the complex magnitude of the reconstructed wave to recover the object wave information from the hologram in (1).

\[
U_R(\xi, \eta) = R(\xi, \eta) \exp\{-j \frac{2\pi}{\lambda_2 f} (\xi x_r + \eta y_r)\} \tag{2}
\]

where \(\lambda_2\) and \(f\) are the wavelength of the light source and the focal length of the Fourier transform lens respectively. The multiplication of the complex magnitude in (2) and the multiplication of the third term and the fourth term in (1) is the object wave diffracted from the hologram.

In this paper, the off-axis holographic watermark is used because it is able to embed high payload and robust to the compression and the geometrical attack. The watermark embedding is performed to superpose the hologram generated from (1) and the original signal. The watermark can be extracted by reconstructing the hologram without the original signal. The multi bits information is came from the signal of the inverse Fourier transform of the multiplied signal between the watermarked signal and the reconstructed signal of (2). The embedded information can be represented by the superposition of the several dots as (3) and the dots can be extracted by (4) independently.

\[
d(x_0, y_0) = \sum_{i} d_i (x_0, y_0) \tag{3}
\]

\[
d(x_i, y_i) = \int \int \omega(x_i, y_j) U_R(\xi, \eta) \times \exp\{j2\pi(\xi x_r + \eta y_r)\} \times \exp\{d(x_0, y_0)\} d\xi d\eta \tag{4}
\]

where \(d(x_0, y_0)\) is the order of the bit information when embedding and extracting in the 2D plain, \(d(x_0, y_0)\) and \(d(x_i, y_i)\) are the embedded data and the extracted data respectively, and \(N\) is the number of the embedded data.

The Fourier coefficients of the object wave (embedded information) when generating the hologram have large variable range because the Fourier spectrum of the most magnitude information is concentrated on the center. This characteristic makes the diffraction effect down and the PSNR of the watermarked signal worse. Therefore, the Fourier coefficients of the object wave are made regularly by multiplying any random-phase factor to the object wave before the transform.

For ensuring the space to embed more information and preventing the extraction of the multi bits information at same time, the real and imaginary part is divided by the off-axis hologram. Because the off-axis hologram divides the reference wave and the object wave which are incident into the record media, we can observe only an image by dividing the real and imaginary part, and the diffraction of the object wave and the reconstructed wave.

### 3. DWT-SVD based Holographic Forensic Marking

In this paper, the subband coefficients of the wavelet transform is taken first SVD and the hologram generated from the forensic mark is embedded into S.
The marked signal $S$ is divided $S$, $U$, $V$ components by second SVD. We suggest an embedding method to get the information by combination of the $S$, $U$, $V$ components from the first and second SVD. For the purpose of the security and the detection performance, the hologram key (H-key) and the detection key (S-key) are used for generation and reconstruction of the hologram.

### 3.1. Hologram Generation and Reconstruction

The hologram generation is completed by the hologram generator (HG). The HG is the hologram generating algorithm of (1) and the inputs are the forensic mark and H-Key. The hologram reconstruction is performed by the hologram reconstruction module (HR) and the HR has a hologram reconstruction algorithm based on (2). The forensic mark would be recovered by the detected hologram and H-Key as the input. We can generate the H-Key from the separate angle $\theta$ and coordinate $r$.

### 3.2. Embedding of Holographic Forensic Mark

The embedding of the holographic forensic mark is performed in the DWT-SVD domain and the flow is as shown in Figure 2. The image embedded the hologram is generated by (5).

$$I_b=IDWT(S_{bh}x(U_{bh}xU_{bh})x(V_{bh}xV_{bh})^T)$$  \hspace{1cm} (5)

In (5), $S_{bh}$ is come from (6) and $S_b$ is the S component obtained from the SVD coefficients of the DWT subband coefficients of the original image. $H_b$ is the hologram come from the forensic mark, and $\hat{\theta}$ is the embedding intensity of the hologram. The suffix b means the subband HL, LH and HH.

$U_b$, $V_b$ are the $U$, $V$ components (orthogonal) come from SVD of the subband coefficients and $U_{bh}$, $V_{bh}$ are the $U$, $V$ components of SVD of $S_b$. The matrix decomposition of SVD is represented by $X=UxSxV^T$, and it is divided a trigonometric matrix $U$, $V$.

The embedding process of the hologram to the original image is as follows,

Step1: 2-level DWT of the original image
Step2: generate $S_b$ and $U_b$, $V_b$ by SVD of the coefficients of a selected subband
Step3: embedding the hologram into $S_b$ by (6)
Step4: generate $S_{bh}$ and $U_{bh}$, $V_{bh}$ by SVD of $S_b$ embedded the hologram
Step5: calculate $U_bxU_{bh}$ and $V_bxV_{bh}$
Step6: reconstruct the subband coefficients by $U_bxU_{bh}$, $V_bxV_{bh}$ and $S_{bh}$
Step7: generate the image embedded the hologram by IDWT of the subband coefficients
Step8: generate the detection key S-key from $U_b$, $V_b$ and $S_{bh}$

### 3.3. Extraction of Holographic Forensic Mark

The hologram extraction is performed in the DWT domain. The marked image is taken DWT and the DWT subband coefficients which are embedded the hologram is decomposed by SVD. The hologram is extracted by the detection key generated in the embedding step. The process is as shown in Figure 3.

$$\text{SVD}(\text{DWT}(I_b)) \Rightarrow S_{bh}x(U_{bh}xU_{bh})x(V_{bh}xV_{bh})^T$$  \hspace{1cm} (7)

$$\text{SVD}(\text{S-Key}) \Rightarrow S_{bh}xU_{bh}xV_{bh}^T$$  \hspace{1cm} (8)

$$U_c=U_b^T x(U_{bh}xU_{bh})=U_{bh}, V_c=V_b^T x(V_{bh}xV_{bh})xV_{bh}$$  \hspace{1cm} (9)

$$S_b = S_{bh}xU_cxV_c$$  \hspace{1cm} (10)
$S_h'$ is the approximation of $S_h$ generated in the embedding step and the input value to recover the forensic mark.

The hologram extraction process is as follows:
Step1: perform 2 level DWT for the image embedding the hologram
Step2: perform SVD for the selected subband coefficients and $S_{bh}$ and $U_b x U_{bh}$, $V_b x V_{bh}$
Step3: generate $S_{bh}$ and $U_b$, $V_b$ by SVD of the $S$-Key
Step4: multiply the transverses of the orthogonal matrix $U_b$, $V_b$ to $U_b x U_{bh}$, $V_b x V_{bh}$ in Step 2
Step5: generate the approximation $S_h'$ of $S_h$ by $U_e$, $V_e$ and $S_{bh}$
Step6: recover the forensic mark $S_h'$ and H-Key

4. Experiments

For the experiments, 512x512 “Lena” image is used and the binary image is used as a forensic mark. In order to ensure the robustness to the compression, the modification and the signal interference in the multi step embedding and detecting, the 1bit information is modulated 2x2 blocks and it can reduce the bit error rate (BER). Figure 4 shows the block patterns for the information 0/1 respectively. The value of the white pixel is 0.7 and the algorithm decides the bit value if the mean value of the symmetric pixels is over the threshold.

![Figure 4. Block patterns for the information 0/1](image)

For embedding 128bits forensic mark, we generated the forensic information randomly and constructed the 32x16 binary image using the block patterns according to the 0 or 1. Figure 5 displays the forensic mark image and the hologram image of the forensic mark image.

Figure 6 depicts the results of the forensic mark from LH band after embedding the marks into 3 bands, LH, HL, and HH. The bit value is estimated if the mean value is over 0.35 or not. In the other bands, HL and HH, we can extract similar forensic mark. Especially, the result of HH band was best. The information is embedded in 3 bands and the total information bits are 128x3=384bits and the PSNR is 40.14[dB].

![Figure 5. Forensic Mark Image and Generated Hologram](image)

Figure 6 shows the results of the embedding in the multiple steps. The image (a) is the extracted mark in the first step with 128bits information in LH band and (b) is the mark in the second step with additional 128bits information in HL band. In the first step embedding, PSNR is 44.91[dB] and 40.82[dB] in the second step, 37.77[dB] in the third step. In the case of Figure 5, PSNR=40.14[dB] with 384bits information, but the multiple embedding case shows PSNR=37.77[dB] in the same information.

Even though we embedded 384bits information for each case, the multiple step case is not good for PSNR.

![Figure 7. Forensic Mark detected in LH band](image)

Figure 8 shows the PSNR variation chart according to the multiple steps. In this case, the 2 level DWT was

![Figure 8. PSNR variation chart according to the multiple steps](image)
applied for embedding the forensic mark; we changed the subband of DWT from 2 level HL band to 1 level HH band. As increasing the step, the PSNR is decreased the range of 4~7[dB] at each step. The embedding intensity is kept as $\alpha=3.5$.

Figure 8. PSNR change by the multiple steps

Figure 9 depicts the payload according to the embedding intensity. If the PSNR is kept 40[dB], the amount of the information to be able to embed is reduced as the intensity is increased. Even if the amount is reduced it is still enough payloads than the spread spectrum method.

In the case of the spread spectrum, it just can embed 48 bits for 3 subbands using 32x32 random sequence under the same experimental condition.

Figure 9. Payload by intensity

Figure 10 shows the detection performance by the quality factor of the JPEG compression. The white pixels and the black pixels can be distinguished until $QF=40$. The mean value of the black pixels is not over 0.05 and the white is over 0.1, so we can configure the threshold= 0.1. If $QF$ is low than 40, the BER is about 5%.

Figure 10. Symmetric Pixels Variation in QF of JPEG Compression

5. Conclusions

In this paper we suggested an effective algorithm which is able to embed the forensic mark at the multiple steps for tracing illegal distribution of the digital content. For this purpose, we used DWT-SVD domain for embedding the forensic mark, and the off-axis hologram was used to make a robust forensic mark. The SVD ensured the algorithm security and enhanced the detecting performance, and the DWT reduced the signal interference when the multiple forensic marks were embedded.

The hologram is robust to geometrical attacks, such as rotation, scale and cropping. Our research group is going to develop more enhanced algorithm for multiple steps over 5 steps.

6. References


9, April 2004, pp. 506-512.


Acknowledgement

Soli Deo Gloria. This research is supported by Ministry of Culture, Sports and Tourism(MCST) and Korea Creative Content Agency(KOCCA) in the Culture Technology(CT) Research & Development Program 2009.