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Linear Weighted Multiple Watermarking in DWT-SVD Domain Through Covariance Analysis

(***Linear weighted watermarking in DWT-SVD domain***)

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***Abstract*— This paper proposes a covariance based multiple watermark embedding using modified normalized principal components watermarking. Multiple watermarking increases the reliability of watermarks against various attacks. Blocks of the host image are selected for multiple watermark embedding by evaluating covariance between the blocks and textures of the watermark. Once the blocks and textures are identified, modified normalized principal components watermarking is applied in DWT-SVD domain to avoid false positive error. Performance of the proposed watermarking technique is analyzed by peak signal to noise ratio, correlation coefficient and structural similarity index. Comparative analysis with other watermarking methods also reveals the better performance of the proposed method.**

Keywords— multiple watermarking, covariance, DWT-SVD, normalized principal components

I. INTRODUCTION

The extensive growth of multimedia contents attracts researchers towards image cryptography, image watermarking and image authentication techniques. Integrity of multimedia contents transferred through various networks is the cause of concern that leads to watermarking schemes to analyze authenticity, copyright and ownership issues [1]. Watermarking algorithms are broadly classified into fragile, semi-fragile and robust methods. Fragile algorithms are the one in which watermarked images don't withstand any image processing or non-image processing attacks [2,3,4,5]. Robust algorithms do not allow any modifications or attacks on the watermarked images [6,7,8,9]. On the other hand, semi-fragile watermarking schemes allow certain image processing steps to be carried out on the watermarked images [10,11,12,13].

As reported in the literature, watermarking schemes are implemented either in spatial or transform domain. Watermarking algorithms in transform domain have gathered momentum because of their robustness against various intentional or non-intentional attacks on the watermarked images. Among the transform domain methods, discrete wavelet transform (DWT) – singular wavelet decomposition (SVD) based watermarking methods are quite popular because of their simplicity. But these methods do suffer from false positive error (FPE) in the extraction process [14].

This issue arises due to S-matrix embedding which has less impact on the host image.

Hence, S-matrix of some other watermark will also lead to the malicious host extraction. This issue can be effectively overcome by modified S-matrix embedding in DWT-SVD domain.

This paper proposes a covariance based multiple watermark embedding on the selected blocks of the host image using modified normalized principal components watermarking in DWT-SVD domain (MNPC-DWT-SVD). Watermark is decomposed into textures using Arnold transform (AT). Covariance is evaluated between the blocks of the host image and textures of the watermark image. Minimum covariance between a block and a texture reveals the maximum similarity between the two. Hence watermark embedding will not have much visual distortion in the host image. Five pairs of blocks and textures are selected based on the minimum covariance strategy. For modified normalized principal components watermarking, S and U matrices of the watermark are multiplied and embedded into the S matrix of the host image using scaling factors or weights derived from the normalized principal components. Performance of this method is evaluated by the metrics such as peak signal to noise ratio in dB (PSNR in dB), correlation coefficient (CC) and structural similarity index (SSIM). Comparative analysis is performed with other methods such as DWT-SVD, redundant DWT-SVD (RDWT-SVD), and normalized principal components based DWT-SVD watermarking (NPC-DWT-SVD).

This paper is organized as follows; Section 2 deals with modified NPC-DWT-SVD watermarking. Experiments and results are given in section 3. This is followed by conclusion in section 4.

II. MODIFIED LINEAR WEIGHTS WATERMARKING IN DWT-SVD DOMAIN

This algorithm splits the host image, $'I_H(x,y)'$ into blocks, $'I_B(s,t)'$. Watermark image, $'I_{WM}(s,t)'$ is also converted into texture like images using AT. Covariance analysis is carried out between each one of the host blocks and all the textures. Then, first five pairs of host blocks and watermark textures are identified with minimum covariance. The five pairs are further processed for watermark embedding in DWT-SVD domain.

A. *Modified NPC-DWT-SVD Watermarking*

The selected blocks of the host image 'I_H' are decomposed into subbands $\{LL_H, LH_H, HL_H, HH_H\}$ by DWT. Similarly watermark image 'IW' is also decomposed into $\{LL_W, LH_W, HL_W, HH_W\}$ subbands. The steps involved in modified NPC based watermarking in DWT-SVD domain are stated below

SVD is applied to both HH_H and HH_W

$$U_H S_H V_H = \mathrm{SVD}\{HH_H\} \tag{1}$$

$$U_W S_W V_W = \mathrm{SVD}\{HH_W\} \tag{2}$$

Modified S_W' matrix [14] for embedding is evaluated by

$$S_W' = U_W * S_W\ S_w \tag{3}$$

Linear weights are derived from the normalized principal components as given below

$$[E, D] = \mathrm{Eigen}\,\{\mathrm{cov}[HH_H, HH_W]\} \tag{4}$$

Where

$$E = \begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{22} \end{bmatrix} \;\&\; D = \begin{bmatrix} D_{11} & . \\ . & D_{22} \end{bmatrix} \tag{5}$$

E – Eigen vectors D – Diagonal matrix with Eigen values

Normalized principal components [15,16,17] PC_1 and PC_2 are evaluated by

If $D_{11} > D_{22}$

$$PC_1 = \frac{E_{11}}{E_{11} + E_{21}};\ PC_2 = \frac{E_{21}}{E_{11} + E_{21}} \tag{6}$$

If $D_{22} > D_{11}$

$$PC_1 = \frac{E_{12}}{E_{12} + E_{22}};\ PC_2 = \frac{E_{22}}{E_{12} + E_{22}} \tag{7}$$

Watermark embedding [18] is given by

$$S_{emb} = PC_1 * S_H + PC_2 * S_W' + PC_2 * S`_w \tag{8}$$

HH sub and of the Watermark embedded image is obtained by

$$HH_{emb} = U_H * S_{emb} * V^T{}_H \tag{9}$$

Watermarked image is derived by applying inverse DWT

$$I_{emb} = IDWT\{LL_H, LH_H, HL_H, HH_{emb}\} \tag{10}$$

The steps involved in modified NPC based linear weights watermarking are given in Fig. 1

Algorithm Steps

The steps involved in the proposed modified NPC based linear weights watermarking are given below

1. Split $I_H(x, y)$ of size 512 X 512 into blocks $I_B(s, t)$ of size 64 X 64
2. Using AT, convert $I_{WM}(s, t)$ into textures (pixel scrambles) of same size. AT produces 48 pixels scrambles for the watermark of size 64 X 64
3. Evaluate covariance between each one of the blocks and all pixel scrambles
4. Identify first five pairs of blocks $I_B^n(s, t)$ and pixel scrambles $I_T^m(s, t)$ with minimum covariance

   Where B - Blocks;

   n - index of the host image blocks;
   n = 1, 2, 3,…, 64
   T -Textures;
   m - index of the pixel scrambles;
   m = 1, 2, 3,…, 48
5. Apply DWT to a pair of $I_B^n(s, t)$ and $I_T^m(s, t)$
6. Apply SVD to HH subband of a host block and a pixel scramble
7. Evaluate normalized principal components PC_1 and PC_2 as stated in section 2.1
8. Compute modified S-matrix of a watermark texture as given in Eq. 3
9. Apply embedding strategy as given in Equation 8 to get a watermark embedded S-matrix, S_{emb}, for the host block
10. Using S_{emb}, reconstruct HH_{emb} subband for the host image
11. Apply IDWT to LL_H, LH_H, HL_H, HH_{emb} to get watermark embedded host block $I_{emb}^n(s, t)$
12. Repeat steps 6 to 11 to all the identified pairs of $I_B^n(s, t)$ and $I_T^m(s, t)$
13. Combine all the watermark embedded blocks with the remaining host blocks to get the watermark embedded image $I_{emb}(x, y)$

III. EXPERIMENTAL RESULTS AND ANALYSIS

Three experiments were conducted to analyze the performance of the proposed watermarking scheme. Performance is analyzed by metrics such as PSNR in dB, SSIM and CC. PSNR measures performance of watermarking quantitatively and other two metrics do perform qualitative performance analysis. Four standard host images with the spatial resolution of 512 X 512 are taken for experiments and given in Fig. 2. All the host images are separated into 64 X 64 blocks for watermark embedding. For decomposition, DWT with 'Haar' wavelet is applied to the images. Watermark image, 'Peppers', with the size of 64 X 64 is embedded into the selected blocks of the host image. The three metrics are evaluated for watermark embedding, host and watermark extractions.

A. *Watermark Embedding Analysis*

Watermark image is scrambled into textures using AT. Then the pairs of host blocks and watermark textures with minimum covariance are selected for embedding process. As stated in section 2, modified S-matrix of a watermark texture is embedded into the S-matrix of the host block.

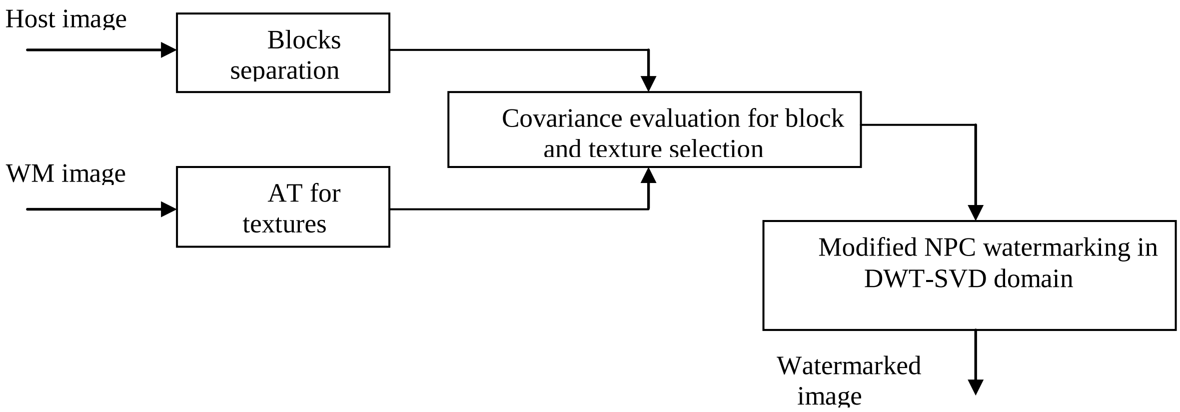

Fig. 1. Modified NPC based linear weights watermarking

(a) (c)

(b) (d)

(e)

Fig. 2. Host images (a) Boat (b) Airplane (c) Zelda (d) Goldhill (e) Watermark image (Peppers)

Once multiple texture embedding is completed in all the selected blocks of the host image, the watermark embedded blocks are combined with the remaining blocks of the host image to reconstruct a watermark embedded image. The performance metrics are evaluated between the watermark embedded host and the original host image. The metrics are tabulated in Table I, II & III. For the proposed method, high PSNR is obtained because the watermark is embedded on the selected blocks of the host image. For the experiments, only five block and texture pairs with minimum covariance are selected for watermark embedding. This selected watermarking in the level of S-matrix of the host blocks do have less impact in the pixel values of the host image. For the same reason, other metrics, SSIM and CC are also maximum. This demonstrates that the watermark embedded image is similar to the original host image.

TABLE I. WATERMARK EMBEDDING (PSNR IN DB)

Methods	Boat	Airplane	Zelda	Goldhill
DWT-SVD	28.67672	27.99832	28.15482	28.66598
RDWT-SVD	28.67497	28.67354	28.67311	28.67523
NPC-DWT-SVD	54.7469	58.71134	61.72735	55.87358
MNPC-DWT-SVD	75.56341	74.27738	80.16847	76.34452

TABLE II. WATERMARK EMBEDDING (CC)

Methods	Boat	Airplane	Zelda	Goldhill
DWT-SVD	0.999555	0.999665	0.999908	0.999551
RDWT-SVD	0.999614	0.99972	0.999934	0.999591
NPC-DWT-SVD	0.99995	0.99998	0.999987	0.999965
MNPC-DWT-SVD	1	0.999999	1	1

TABLE III. WATERMARK EMBEDDING (SSIM)

Methods	Boat	Airplane	Zelda	Goldhill
DWT-SVD	0.995223	0.997086	0.993116	0.993879
RDWT-SVD	0.995369	0.997149	0.993223	0.994083
NPC-DWT-SVD	1	1	1	1
MNPC-DWT-SVD	1	1	1	1

B. Host and Watermark Extraction

For host and watermark extraction, the reverse steps of watermark embedding are carried out with the knowledge of the host and the watermark images. The extracted host is compared with original host and the metrics are tabulated in Table IV, V & VI. High PSNR represents high quantitative similarity between the extracted host and original host. Other two metrics also exhibit the highest qualitative similarity among the images. The same analysis is demonstrated for watermark extraction and the metrics are tabulated in Table VII, VIII & IX.

TABLE IV. HOST EXTRACTION (PSNR IN DB)

Methods	Boat	Airplane	Zelda	Goldhill
DWT-SVD	297.2019	299.5996	294.6514	293.1579
RDWT-SVD	274.6432	276.3938	275.5481	274.2217
NPC-DWT-SVD	315.3405	312.5326	318.1948	316.1987
MNPC-DWT-SVD	326.2418	324.268	329.4961	328.662

TABLE V. HOST EXTRACTION (CC)

Methods	Boat	Airplane	Zelda	Goldhill
DWT-SVD	1	1	1	1
RDWT-SVD	1	1	0.999999	1
NPC-DWT-SVD	1	1	1	1
MNPC-DWT-SVD	1	1	1	1

TABLE VI. HOST EXTRACTION (SSIM)

Methods	Boat	Airplane	Zelda	Goldhill
DWT-SVD	1	1	1	1
RDWT-SVD	0.999997	0.999997	0.999995	0.999995
NPC-DWT-SVD	1	1	1	1
MNPC-DWT-SVD	1	1	1	1

TABLE VII. WM EXTRACTION (PSNR IN DB)

Methods	Boat	Airplane	Zelda	Goldhill
DWT-SVD	285.4239	286.0401	289.321	286.1962
RDWT-SVD	254.5743	256.3529	255.4124	254.0459
NPC-DWT-SVD	318.3756	318.5849	318.6773	318.4863
MNPC-DWT-SVD	319.7916	327.512	327.1034	320.4834

TABLE VIII. WM EXTRACTION (CC)

Methods	Boat	Airplane	Zelda	Goldhill
DWT-SVD	1	1	1	1
RDWT-SVD	0.999953	0.999967	0.999958	0.999946

NPC-DWT-SVD	1	1	1	1
MNPC-DWT-SVD	1	1	1	1

TABLE IX. WM EXTRACTION (SSIM)

Methods	Boat	Airplane	Zelda	Goldhill
DWT-SVD	1	1	1	1
RDWT-SVD	0.999436	0.999521	0.999397	0.999279
NPC-DWT-SVD	1	1	1	1
MNPC-DWT-SVD	1	1	1	1

IV. CONCLUSION

This paper proposed a linear weighted multiple watermarking using normalized principal components and covariance estimation in DWT-SVD domain. Multiple watermarking in the selected blocks of the host image, texture watermarking and modified S-matrix embedding contribute to the elimination of false positive error happening in DWT-SVD watermarking methods. Blocks and texture pairs are selected for watermark embedding based on minimum covariance. As the textures of the watermark are embedded on the selected blocks of the host image, impact of watermark embedding is less in the original host image. Quantitative and qualitative metrics evaluated in the embedding and extraction steps also substantiate the performance of the proposed watermarking method.

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