Survey of Frequency Domain Image Watermarking Techniques

Petr Cika

***Abstract*—Digital image watermarking methods are suitable for make a simple copyright protection on digital images. There exist a lot of digital image watermarking methods in all over the word. These methods uses spatial or transformation domain to insert for example copyright information (watermark) into original image. Mostly, frequency domain is used to watermark insertion. Especially discrete cosine transforma and discrete wavelet transform are used in many watermarking techniques. Together with these transforms also other methods, like singular value decomposition, forward error-correction codes, etc., are used to increase watermark robustness. This paper describes influence of singular value decomposition and forward error-correction codes, concretely on watermark robustness.**

***Index Terms*—fec, dct, dwt, svd, watermarking**

I. Introduction

DIGITAL watermarking is a method that is used widely for protecting the copyright of digital contents, especially digital images and digital videos. The first group of visible watermarks are generally known and used for example as TV channel logos. This article deals with the second group of invisible watermarks.

Generally speaking, invisible watermarks can be inserted in spatial domain or in transform domain [1]. There exist lots of methods which use the spatial domain for watermark insertion [2], [3]. The most famous and firstly published method uses the least significant bits of the image data for watermark insertion. However, most of these methods are not robust enough against todays attacks.

This paper focuses on invisible watermarks and techniques that use transform (frequency) domain for watermark insertion. Particularly, methods which use discrete cosine transform and singular value decomposition, discrete wavelet transform and singular value decomposition along with an influence of error-correction codes on inserted watermark are described in this paper. All methods described in the next few paragraphs are finally tested and compared.

II. Frequency Domain Watermarking Techniques

Frequency domain representation of digital image is in most cases acquired using two dimensional DCT (2D-DCT) or two dimensional DWT (2D-DWT). 2D-DCT is usually applicable on the square image data (matrix) of dimension 8x8 pixels. Similarly to other transforms, the 2D-DCT attempts to decorrelate the image data. Low frequencies are concentrated in the top left corner of the transformed matrix, high frequencies are concentrated in the bottom right corner. This transform is used in the well-known JPEG and MPEG compressions schemes. The second transform frequently used in image and video compressions schemes is the 2D-DWT. The 2D-DWT decomposes the original image into four bands, the watermark could be embedded into all frequencies.

There exist many techniques uses additional function to increase robustness of inserted watermarks. One possibility method to increase robustness of inserted watermark in digital image is Singular Value Decomposition (SVD). SVD, as a general linear algebra technique, is used in a variety of applications, for example in watermarking. Modifying the singular value decomposition of the image is one of the most prevalent techniques in transform domain watermarking. SVD is described by the equation

$$A = USV^T \tag{1}$$

where the diagonal entries of S matrix are the singular values, the U matrix contains the left singular vectors and the V matrix contains the right singular vectors. Each of the new matrices has the same dimension as the original matrix A. The important fact is that each s singular value from the singular matrix

$$\begin{pmatrix} s_1 & ... & 0 \\ ... & ... & ... \\ 0 & ... & s_i \end{pmatrix} \tag{2}$$

specifies the luminance value of image layers while the corresponding pair of singular vectors specifies the geometry of the image layer.

The second possibility to increase watermark robustness is using of forward error correction codes during watermark embedding process.

There will be described two digital image watermarking methods in next chapters. The first one uses DCT and SVD, the second one uses DWT and SVD to watermark insertion. Further, the possibility of using of forward error correction codes will be described. Finally, all described methods and watermarks will be tested against various attacks.

III. Watermarking Technique with 2D-DCT-SVD

Principle of first tested watermarking method which uses 2D-DCT together with SVD will be described in this chapter. This method is derived from methods described in [4], [5], [6], [7].

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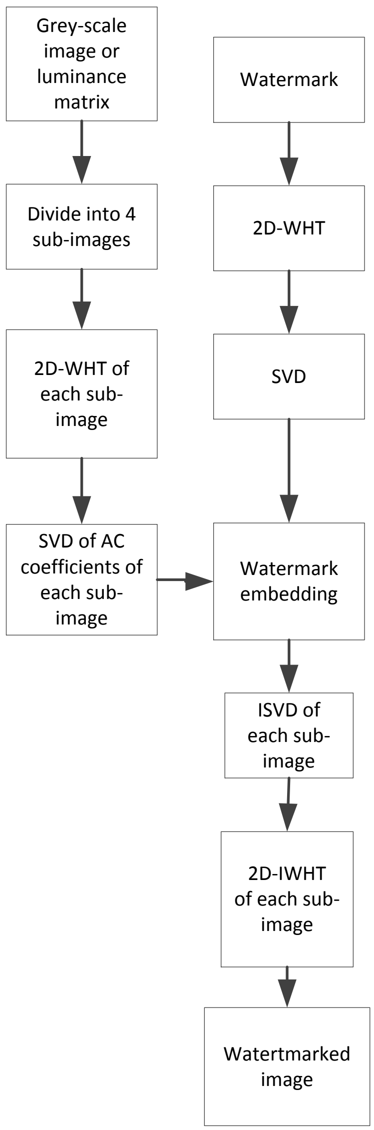

Fig. 1. Watermark embedding process

A. Embedding process

Following steps describe the embedding process (figure 1) of the proposed watermarking methods:

1) A gray-scale image I is divided into 4 sub-images $I_1, ..., I_4$.
2) 2D-DCT is applied to each sub-image $I_1, ..., I_4$.
3) Singular value decomposition is applied to each sub-image transformed from the step 2

$$A_k = U_k S_k V_k^T, \tag{3}$$

where k specifies the sub-image.

4) 2D-DCT is applied to a whole watermark image W. Space dimensions of the inserted watermark image must be equal to space dimensions of sub-images I_k.
5) Singular value decomposition is applied to the transformed watermark W

$$A_w = U_w S_w V_w^T, \tag{4}$$

6) Singular values of each sub-image are modified by singular values watermark

$$s_{ki}^* = s_{ki} + \alpha s_{wi}, \tag{5}$$

where $i = 1, ...n$, (n is number of singular values of sub-image), s_{ki} are singular values of S_k, s_{wi} are singular values of S_w and α is a scale factor.

7) New singular matrix S_k^* is defined from s_{ki}^* values .
8) Four sets of modified 2D-DCT coefficients are obtained by the equation

$$A_k^* = U_k S_k^* V_k^T, \tag{6}$$

where $k = 1, ...n$, and the watermarked image can be obtained using inverse 2D-DCT.

B. Extraction process

Following steps describe the extraction process (figure 2) of the proposed watermarking methods:

1) An image watermarked with embedding process is divided into 4 sub-images $I_{w1}, ..., I_{w4}$.
2) 2D-DCT transformation is applied to each sub-image $I_{w1}, ..., I_{w4}$.
3) Singular value decomposition is used to transformed image.

$$A_t = U_t S_t V_t^T \tag{7}$$

4) 2D-DCT transformation and singular value decomposition are applied to the original imageas same as in the embedding process.
5) Singular values of watermark are extracted from each sub-image I_w and orginal sub-image I at the same position by using the equation

$$s_{wei}^* = (s_{ti} - s_{ki})/\alpha, \tag{8}$$

where k specifies a sub-image position, $i = 1, , n$ specifies singular values, s_{wei}^* are singular values of extracted watermark.

6) Inverse SVD is applied to each set to construct four extracted watermark images

$$A_{wei}^* = U_w S_{wei}^* V_w^T \tag{9}$$

7) Inverse 2D-DCT is applied to each set to construct four extracted watermark images.
8) The best extracted watermark is chosen according to the computed NCC.

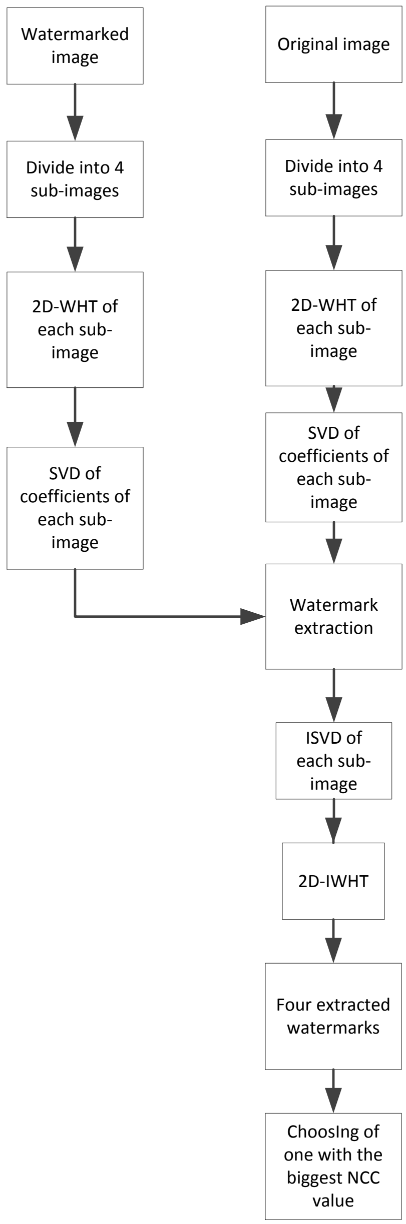

Fig. 2. Watermark extraction process

IV. Watermarking Technique with 2D-DWT-SVD

Principle of second tested watermarking method which uses 2D-DWT together with SVD will be described in this chapter. This method is derived from methods described in [4], [5], [6], [7].

A. Embedding Process

Following steps describe the embedding process (figure 3) of the proposed watermarking methods:

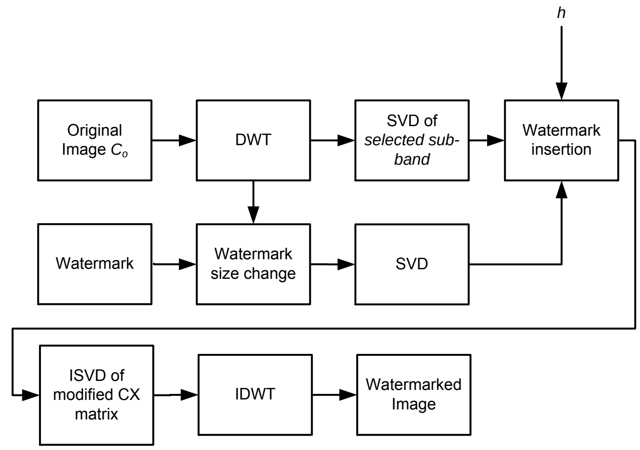

Fig. 3. Watermark embedding process

1) Original image C_o is transformed into the DWT domain (only the first pyramid decomposition). Four subbands (CA, CV, CH, CD) are computed.
2) One of created subbands is used for watermark embedding process. In case of CA sub-band we get generally the best results but there is a problem with visibility of watermark. Rather than CA the other subband should be used. A selected sub-band CX is SVD transformed by equation

$$CX = U_{CX} S_{CX} V_{CX}^T, \tag{10}$$

where CX is the selected sub-band, singular values are the diagonal entries of S_{CX}, U_{CX} is a matrix of left singular vectors, V_{CX} is a matrix of right singular vectors. All matrices have same dimension as the original CX.
3) Spatial dimensions of watermark image W are modified according dimesions of the selected sub-band CX. The modified watermark W_m is decomposed by equation

$$W_m = U_{W_m} S_{W_m} V_{W_m}^T. \tag{11}$$

4) The S_{Wm} matrix is used for watermark embedding. The watermark embedding procces follows equation

$$s_{CXi}^* = s_{CXi} + h s_{W_{mi}}; i = 1, ..., x, \tag{12}$$

where i is the position of singular value of CX sub-band, h is the factor of watermark robustness.
5) CX_m is computed by means of $S*_{CX}$¿

$$CX_m = U_{CX} S_{CX}^* V_{CX}^T. \tag{13}$$

6) Finnaly, CX_m sub-band together with other three sub-bands are used for inverse DWT transform and watermark embedding process is finished.

B. Extraction process

Whole watermark extraction process is shown in figure 4.

1) Original image C_o is transformed into DWT domain.

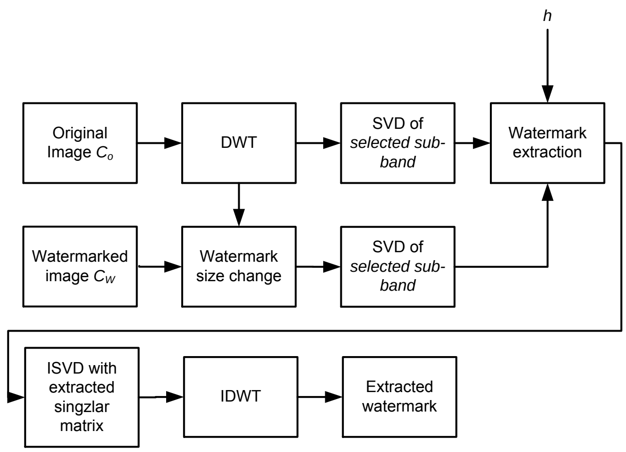

Fig. 4. Watermark extraction process

2) Watermarked image C_w is transformed into DWT domain.
3) Selected sub-band, CX from original image and CX_W from watermarked image,are is used for watermark extraction. The sub-band must be same as in embedding process.
4) Singular value decompositions for selected sub-bands of original and watermarked images are computed¿

$$CX = U_{CX} S_{CX} V_{CX}^T, \tag{14}$$

$$CX_W = U_{CX_W} S_{CX_W} V_{CX_W}^T. \tag{15}$$

5) Singular values of watermark are extracted by equation

$$s_{WEi}^* = \frac{(s_{CX_{Wi}} - s_{CX_i})}{h}, i = 1, 2, ...n, \tag{16}$$

where i is a position of singular value in original image C_o.
6) Extracted singular matrix S_{WE} is used together with right singular value matrix V_W and left singular value matrix U_W of original Watermark W to watermark extraction.
The acquired singular value matrix is used for inverse singular value decomposition. The right and left singular value with extracted singular value matrix are used for it. The inverse singular value decomposition uses the equation

$$W' = U_W S_e^* V_W^T. \tag{17}$$

V. Forward Error Correction Codes

Forward Error-correcting Codes (FEC) are usually used during digital signal transmissions in many areas. There exist two types of FEC: block based codes and convolutional codes. We will basically describe block based FEC. The block based FEC are based on addition of redundant information to an original message at the encoder side. This redundant information helps at decoder side to detect or correct possible error. Many variations of block based FEC exist. We used BCH codes, namely BCH (15,5,3) and BCH (15,11,5), to test of impact FEC on described watermarking systems.

Watermark was before insertion secured with BCH code to possible increasing of its robustness.

VI. Evaluation

We use Checkmark benchmark tool to evaluate of watermark robustness. Checkmark easily carries out attacks on watermarked image and returns the results of watermark extraction success. There arer 4 groups of attacks in Checkmark:

- removal attacks,
- geometric attacks,
- cryptographic attacks,
- protocol attacks.

Various images were used as original images (totaly one hundred images), various logos were used as watermark image to test the proposed methods. The scale factor 0.16 same as in [7] was used as a trade-off between watermark invisibility and robustness. The method developed in this paper was compared with the methods that use 2D-DCT-SVD and 2D-DWT-SVD domain described in [7]. A new method has better results than 2D-DCT-SVD but worse results than 2D-DWT-SVD. Table in Figure **??** shows the results of watermark extraction after the selected attacks.

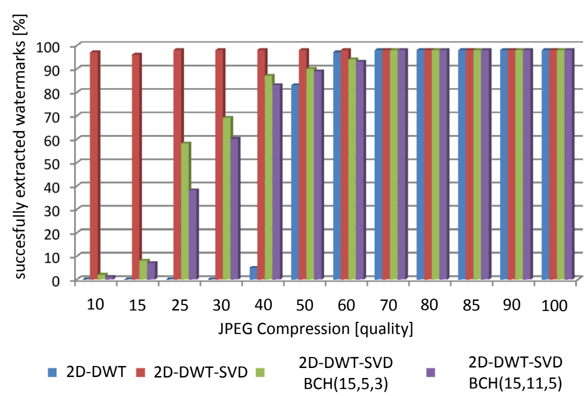

Fig. 5. JPEG attack - DWT watermarking

VII. Conclusion

The paper describes a watermarking methods based on two dimensional discrete cosine transformations and singular value decomposition; two dimensional discrete wavelet transformations and singular value decomposition. As an additional BCH forward error correction codes were implemented to increase of watermark rubustness. Both watermarking methods were tested against a lot of attacks available in Checkmark, a benchmark tool. Results introduced in graphs at the end of this paper show robustness of wtaermark which was inserted bz means of described methods.

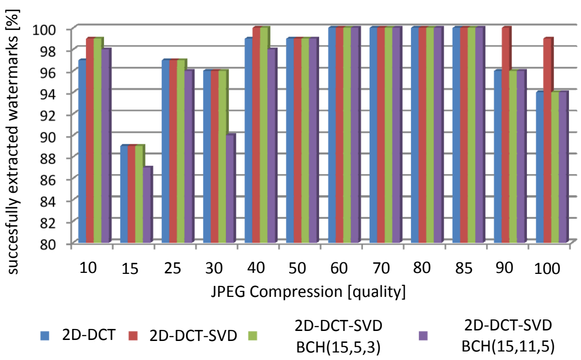

Fig. 6. JPEG attack - DCT watermarking

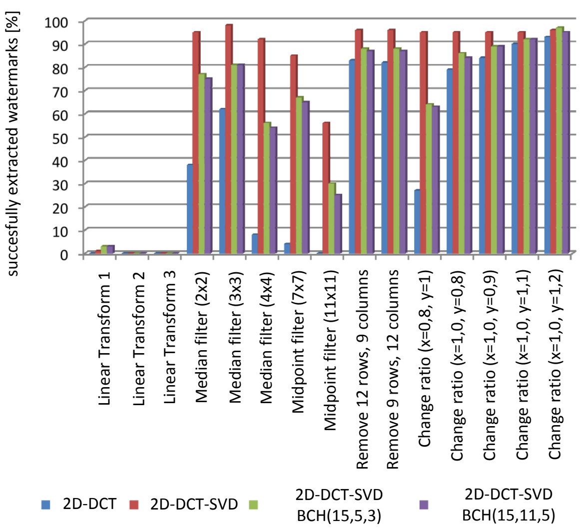

Fig. 7. Various attacks - DWT watermarking

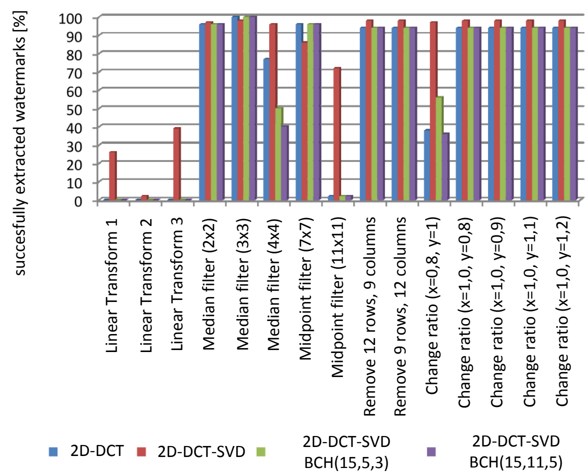

Fig. 8. Various attacks - DCT watermarking

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