SVD-based Digital Image Watermarking on approximated Orthogonal Matrix

Yevhen Zolotavkin and Martti Juhola
Computer Science, School of Information Sciences, University of Tampere, Kanslerinrinne 1, Tampere, Finland

Keywords: Digital Image Watermarking, Singular Value Decomposition, Robustness, Distortions, Transparency.

Abstract: A new watermarking method based on Singular Value Decomposition is proposed in this paper. The method uses new embedding rules to store a watermark in orthogonal matrix U that is preprocessed in advance in order to fit a proposed model of orthogonal matrix. Some experiments involving common distortions for grayscale images were done in order to confirm efficiency of the proposed method. The robustness of watermark embedded by our method was higher for all the proposed rules under condition of jpeg compression and in some cases outperformed existing method for more than 46%.

1 INTRODUCTION

Multimedia is becoming increasingly important for human communication. In some cases the protection of multimedia from unauthorized usage is a critical requirement. Existing and widely used techniques in Digital Right Protection (DRP) do not always provide reliable defence against cybercriminals. One of the main difficulties is connected with degradation of quality of media content caused by application of DRP related tools. Indeed value of perceptual content of media is of the same importance as the question of ownership. The situation is complicated by increasing number of multimedia processing tools that do not contradict officially with DRP policy, but can introduce some specific distortions like, for example, compression. New and more sophisticated methods are needed to satisfy the requirements which complexity is growing.

One of the branches of DRP is Digital Image Watermarking (DIW). The needs of DIW could be different depending on a particular application. For example, it might be required that a watermark resists as much influence as possible (robust watermarking) (Barni, 1997), resists some kinds of influence and indicates presence of other kinds (semi-fragile watermarking) (Altun, 2006); (Pei, 2006), and just indicates (fragile) (Fridrich, 2002).

In order to increase robustness under some constraint that somehow represents invisibility (or transparency) many methods have been proposed during the last 20 years (Cox, 2007). The most successful among them are methods operating in transform domain. Widely used transforms are DFT, DCT, DWT (Fullea, 2001); (Lin, 2000). Those well-known transforms are parameterized in advance and do not depend on an image fragment being transformed. Therefore only a set of coefficients is important to represent a fragment according to a particular transform. However usually few coefficients in the set are used for watermarking.

The drawback is that number of significant coefficients of transformed fragment (and significance of some coefficients as well) could vary between different fragments (Xiao, 2008). Consequently different parts of a watermark could be embedded with non-equal robustness that worsens the total extraction rate under an assumption of some kind of distortion.

Another concern is that embedding of a watermark requires quantization of coefficients. A proper robustness-transparency trade-off for a particular application requires different quantization steps for different fragments. However information about quantization steps should be transmitted separately.

Different type of transform is provided by Singular Value Decomposition (SVD). It assures that the number of coefficients encapsulating image fragment's features is small and constant. These coefficients form a diagonal in a matrix of singular values. However SVD is a unique transform which

Zolotavkin Y. and Juhola M..
SVD-based Digital Image Watermarking on approximated Orthogonal Matrix.
DOI: 10.5220/0004507903210330
In *Proceedings of the 10th International Conference on Security and Cryptography* (SECRYPT-2013), pages 321-330
ISBN: 978-989-8565-73-0

is different for every fragment and information about the transform is in left and right orthonormal matrices. Utilization of singular values for watermarking provides good trade-off between robustness and invisibility (Yongdong, 2005).

Though, elements of left and right orthonormal matrices could also be used for watermarking. The main complication for modification of elements of left and right orthonormal matrices is that matrices can become non-orthogonal. This considerably worsens robustness of a watermark.

The main contribution of this paper is to provide a watermarking method that modifies left orthonormal matrix in a way it remains orthonormal. Another contribution is utilization of different embedding rules that provide different robustness-transparency trade-off which improves flexibility (adjustability) of watermarking.

The rest of the paper is organized as following: a short review of relevant watermarking methods exploiting SVD is given in the Section 2; Section 3 bears our own approach which is described in detail; then, some experimental results are represented in Section 4 followed by a discussion of their importance in Section 5; finally, in Section 6 the paper is concluded by general remarks regarding relevance of our approach and its influence on future research.

2 SVD-BASED WATERMARKING

Watermarking methods utilizing SVD have become especially popular during the last 10 years.

This transform decomposes image fragment I on two orthogonal matrices U and V and diagonal matrix S containing singular values:

$$I = U \cdot S \cdot V^T. \quad (1)$$

Virtually any component from such decomposition can be used for watermark embedding. There are SVD-based watermarking methods that are blind (Modaghegh, 2009), semi-blind (Manjunath, 2012) and non-blind (Dharwadkar, 2011). In spite of that the classification is quite clear, some methods, for example, state they do not require for extraction any additional media except a key, but during watermarking the region of embedding is carefully chosen to optimize robustness-transparency trade-off (Singh, 2012). Evidently it is not absolutely fair to compare performance of pure blind methods with random key toward performance of such region specific methods as the latter require new key (different size) for each new image which is a lot of additional information.

Starting from the first methods modifying just the biggest singular value of decomposed image fragment (Sun, 2002), continued further by more sophisticated methods combining DCT-SVD (Lin, 2000); (Manjunath, 2012); (Quan, 2004), DWT-SVD (Dharwadkar, 2011); (Fullea, 2001); (Ganic, 2004) and methods optimizing trade-off between robustness and transparency for SVD-based watermarking (Modaghegh, 2009) only few among those approaches consider for embedding orthogonal matrices U and V. The papers discussing blind embedding in orthogonal matrix are (Chang, 2005) (Tehrani, 2010) where watermarking methods that operate on U are proposed. The difference between them is that in (Tehrani, 2010) some additional block-dependent adjustment of a threshold is done. Realizations and computational requirements for both methods are quite simple. However, their impact is not only in increased robustness compared, for example, to (Sun, 2002). The methods also could be modified in order to embed larger watermarks. The idea to switch from standard approach of modification of one singular value (as it is usually done in most SVD-based watermarking schemes) to modification of the first column in U provides better adaptation to robustness-transparency requirement. The first column contains several elements that are of equal significance. Their significance is the same as it is for the biggest singular value which is clear when equation (1) is rewritten in a different form:

$$I = \sum_i S_{i,i} \cdot U_i \cdot V_i^T, \quad (2)$$

where U_i and V_i are corresponding columns of U and V respectively. Being constructed from i different significance layers image fragment I has scaling factor $S_{i,i}$ on each layer. Adoptive quantization of the first scaling factor is not always the best alternative for watermarking because it requires transmission of additional information about quantization steps. Therefore it would be more beneficial to modify the first layer in a more sophisticated manner that provides adaptation which purely corresponds to blind strategy. Such attempt is made by Chang (2005) and Tehrani (2010) by introducing a rule with a threshold. The rule is applied to a pair of elements in the first column of U and can be used for embedding with different robustness-transparency rate for each block.

Nevertheless approaches presented by Chang (2005) and Tehrani (2010) have some disadvantages because the authors did not develop a tool to achieve orthogonality and normalization of modified matrix

U. On the other hand SVD guarantees that during extraction of a bit of a watermark from a square block all three resulting matrices are orthogonal. Therefore matrices that were used to compose a block during embedding phase are not equal to the matrices calculated during extraction phase. This fact obviously could cause misinterpretation of a bit of a watermark. Another disadvantage of Chang's (2005) and Tehrani's (2010) approaches is that they used only one embedding rule that considers only two out of four elements in a column. Obviously there is a better way to minimize distortions of embedding if more elements are taken into account.

In order to increase the performance of SVD-based blind watermarking in U domain some improvements are proposed in this paper. First we provide that modified U-matrix is orthonormal which improves robustness. Second we propose different embedding rules that maintain different robustness-transparency trade-off which improves flexibility. Third we minimize embedding distortions which reduces visual degradation of original image.

3 PROPOSED METHOD

Taking into account disadvantages of previously proposed SVD-based watermarking methods new approach is considered in this section. The improvements incorporated in our approach provide that altered U matrix is orthogonal and normalized. Different embedding rules are also proposed.

Satisfying orthogonality requirement would consequently imply better robustness as all the changes introduced to the most robust part of a matrix (the first column) would not have projections on other dimensions (defined by second, third and fourth columns) except the dimension defined by that part. In order to provide this a special kind of approximation of an initial orthogonal matrix is proposed.

Another improvement considered to enhance robustness while preserving most of an original image is normalization of altered orthogonal matrix. Even in case each of original orthogonal matrices defined by SVD is normalized, embedding of a watermark according to (Chang, 2005); (Tehrani, 2010) cancels this quality. In contrast to that our embedding method assures each watermarked orthogonal matrix is normalized.

The way watermark bits are interpreted also significantly influences robustness. The only kind of matrix elements interpretation described in (Chang, 2005), (Tehrani, 2010) is the comparison of absolute values of the second and the third elements in the first column. In some cases we could greatly benefit from different ways of interpretation that take into account more elements. Our method of embedding utilizes five different embedding rules where each rule has an advantage under an assumption of some kind of distortion.

3.1 Approximation of Orthogonal Matrix

The approximation of an initial orthogonal matrix proposed in this paper is based on 4x4 matrix that can be described by 4 variables in different combinations. Each combination creates an entry in a set. One matrix A from the possible set is represented as following:

$$A = \begin{bmatrix} -a & c & d & b \\ d & -b & a & c \\ b & d & -c & a \\ c & a & b & -d \end{bmatrix}. \tag{3}$$

This matrix is always orthogonal and under an assumption single row (or column) is normalized the whole matrix is normalized too. Similarly to widely used basis functions this matrix is described compactly (just 4 variables) but in contrast to them each separate element in a row (or column) is free from being functionally dependent on others. Such a quality makes these matrices quite suitable for accurate and computationally light approximations of original orthogonal matrices obtained after SVD of square image fragments. Moreover every matrix from the set is a distinctive pattern which could be used to assess the distortions introduced after watermark is embedded. Optionally this distinction could be used to determine during extraction which matrix from equally suitable U and V caries watermark's bit. The whole set of proposed orthogonal matrices and option to choose between embedding in U or V is necessary to achieve minimal total distortion that consists of an approximation error and a distortion caused by embedding according to some rule.

There could be several approximation strategies considering models from the proposed set of orthogonal matrices. The main idea of embedding is to provide extraction of watermark bits from orthogonal matrices obtained after SVD with highest possible rate while preserving high enough image quality. Extraction is possible if during embedding a watermarked image fragment is composed using one diagonal matrix S and two orthogonal matrices U_w

and V (here U_w is defined to store a bit).

Suppose now we are preparing (or approximating) the first orthogonal matrix U for embedding, so the result is U_w^p, but the second orthogonal matrix V remains unchanged. As we do not embed in singular values there is no need to care about the content of the diagonal matrix except the requirement that it should be diagonal. So let modified matrix of singular values be S^* and possibly different from original S. Having the original image fragment I of size 4x4 it can be written:

$$\left(U_w^p\right)^T \cdot I \cdot V = S^*. \tag{4}$$

Note that in case of such approximation strategy it is only required to satisfy twelve off-diagonal elements of S^* are as small as possible (in Least Squares sense). Then after approximation is done those twelve elements should be put to zero, so approximation error causes some distortion of image fragment before the actual embedding.

Another approximation strategy is to provide both S and V are unchanged. In that case it is necessary to approach:

$$U_w^p \cdot S \cdot V^T = I. \tag{5}$$

This is more challenging task as it is required to match sixteen pixels as close as possible using the same model of orthogonal matrix defined by just four variables. However, this kind of approximation strategy could have some advantage in perceptual sense because singular values are preserved.

For our particular realization of watermarking method it was decided to limit watermark embedding by the first kind of approximation only. In order to show in more details the approximation with proposed orthogonal matrix let us substitute the matrix product $I \cdot V$ in (4) with 4x4 matrix B:

$$\left(U_w^p\right)^T \cdot B = S^*. \tag{6}$$

Now let's substitute $\left(U_w^p\right)^T$ with orthogonal matrix A in (3):

$$A \cdot B = S^*. \tag{7}$$

Matrix S^* for simplicity could be transformed from 4x4 to 1x16 vector S_v^* by rearranging elements of S^* row by row which will lead to the following equation:

$$[a \;\; b \;\; c \;\; d] \cdot B^* = S_v^*, \tag{8}$$

where

$$B^* = \begin{bmatrix} -B_{1,1} & -B_{1,2} & -B_{1,3} & -B_{1,4} & B_{3,1} & B_{3,2} & B_{3,3} & B_{3,4} & B_{4,1} & B_{4,2} & B_{4,3} & B_{4,4} & B_{2,1} & B_{2,2} & B_{2,3} & B_{2,4} \\ B_{4,1} & B_{4,2} & B_{4,3} & B_{4,4} & -B_{2,1} & -B_{2,2} & -B_{2,3} & -B_{2,4} & B_{1,1} & B_{1,2} & B_{1,3} & B_{1,4} & B_{3,1} & B_{3,2} & B_{3,3} & B_{3,4} \\ B_{2,1} & B_{2,2} & B_{2,3} & B_{2,4} & B_{4,1} & B_{4,2} & B_{4,3} & B_{4,4} & -B_{3,1} & -B_{3,2} & -B_{3,3} & -B_{3,4} & B_{1,1} & B_{1,2} & B_{1,3} & B_{1,4} \\ B_{3,1} & B_{3,2} & B_{3,3} & B_{3,4} & B_{1,1} & B_{1,2} & B_{1,3} & B_{1,4} & B_{2,1} & B_{2,2} & B_{2,3} & B_{2,4} & -B_{4,1} & -B_{4,2} & -B_{4,3} & -B_{4,4} \end{bmatrix}.$$

Equation (8) can be simplified by ignoring 1, 6, 11 and 16 columns and elements of B^* and S_v^* respectively because for the current kind of approximation diagonal elements of S^* are not important. By doing so we will get B^{**} and zero vector $\mathbf{0}_{1\times12}$:

$$B^{**} = \begin{bmatrix} -B_{1,2} & -B_{1,3} & -B_{1,4} & B_{3,1} & B_{3,3} & B_{3,4} & B_{4,1} & B_{4,2} & B_{4,4} & B_{2,1} & B_{2,2} & B_{2,3} \\ B_{4,2} & B_{4,3} & B_{4,4} & -B_{2,1} & -B_{2,3} & -B_{2,4} & B_{1,1} & B_{1,2} & B_{1,4} & B_{3,1} & B_{3,2} & B_{3,3} \\ B_{2,2} & B_{2,3} & B_{2,4} & B_{4,1} & B_{4,3} & B_{4,4} & -B_{3,1} & -B_{3,2} & -B_{3,4} & B_{1,1} & B_{1,2} & B_{1,3} \\ B_{3,2} & B_{3,3} & B_{3,4} & B_{1,1} & B_{1,3} & B_{1,4} & B_{2,1} & B_{2,2} & B_{2,4} & -B_{4,1} & -B_{4,2} & -B_{4,3} \end{bmatrix},$$

$$[a \;\; b \;\; c \;\; d] \cdot B^{**} = \mathbf{0}_{1\times12}. \tag{9}$$

It is natural to suggest that simplest solution for (9) is $a = b = c = d = 0$, but taking into account requirement for A to be normalized the solution is not as trivial:

$$\begin{cases} [a \;\; b \;\; c \;\; d] \cdot B^{**} = \mathbf{0}_{1\times12} \\ a^2 + b^2 + c^2 + d^2 = 1 \end{cases}. \tag{10}$$

Obviously such a regularized overdetermined system represents non-linear Least Squares task.

For further embedding it is required to prepare a set of approximated orthogonal matrices where matrix A is just one possible variant for final decision.

Five embedding rules were introduced to improve robustness. Each rule is a condition that could be satisfied in different ways, so we tried to minimize distortions introduced on that step too. Thanks to simplicity of our orthogonal matrix model minimization of embedding distortions can also be done quite easily. Suppose that as a result of watermark embedding matrix A has been changed and become A^*. Because it is required to keep A^* normalized we will accept for further simplicity that there is some vector $[\Delta a, \Delta b, \Delta c, \Delta d]$ with length 1 which is orthogonal to $[a, b, c, d]$ and A^* is formed from

$$a^* = \sqrt{1-n^2}\cdot a + n\cdot \Delta a,\ b^* = \sqrt{1-n^2}\cdot b + n\cdot \Delta b;$$
$$c^* = \sqrt{1-n^2}\cdot c + n\cdot \Delta c,\ d^* = \sqrt{1-n^2}\cdot d + n\cdot \Delta d;$$

where $0 \le n \le 1$. The result of extraction of a watermarked image fragment from unwatermarked will be:

$$A\cdot S^*\cdot V^T - A^*\cdot S^*\cdot V^T = (A-A^*)\cdot S^*\cdot V^T. \quad (11)$$

Matrix $A - A^*$ is orthogonal as A^* has the same structure as A. Consequently the Sum of Square Residuals (SSR) between watermarked and unwatermarked fragments can be defined as:

$$SSR = norm^2(A-A^*)\cdot \sum_{i=1}^{4}(S_{i,i}^*)^2 = \quad (12)$$
$$= norm^2\left(A-\left(\sqrt{1-n^2}\cdot A + n\cdot \Delta A\right)\right)\sum_{i=1}^{4}(S_{i,i}^*)^2.$$

Here ΔA is formed from $\Delta a, \Delta b, \Delta c, \Delta d$ and is normalized. Further simplification taking into account the previously made assumptions will produce an equation:

$$SSR = 2\left(1-\sqrt{1-n^2}\right)\cdot \textstyle\sum_{i=1}^{4}(S_{i,i}^*)^2. \quad (13)$$

According to (13) distortion of image fragment caused by watermark embedding in our method depends on the length of the vector added to the first column of orthogonal matrix A and does not depend on a vector's orientation in contrast to the method proposed in (Chang, 2005), (Tehrani, 2010). This quality could greatly simplify procedure for minimization of watermarking distortions and enable more different embedding rules to be used. Equation (13) also provides an understanding that the same embedding amplitude could lead to different distortions in different image fragments because of influence of singular values.

3.2 Embedding Rules

Proposed embedding rules could be split in two groups. The first group consists of rules $L1_4$, $L2_4$ and $L\infty_4$ that utilize all the four elements of the first column of orthogonal matrix for both embedding and retrieving. The second group consists of rules $L1_2$ and $L2_2$ that utilize just two elements for retrieving, however, could change four elements for embedding because optimization takes place under normalization constraint. Further suppose we are embedding bit b in U with a positive non-zero threshold T:

$$L1_4: (-1)^b \cdot \left(\left\|\left(U_{1,1}^*, U_{2,1}^*\right)\right\|_1 - \left\|\left(U_{3,1}^*, U_{4,1}^*\right)\right\|_1\right) \ge T;$$

$$L2_4: (-1)^b \cdot \left(\left\|\left(U_{1,1}^*, U_{2,1}^*\right)\right\|_2 - \left\|\left(U_{3,1}^*, U_{4,1}^*\right)\right\|_2\right) \ge T;$$

$$L\infty_4: (-1)^b \cdot \left(\left\|\left(U_{1,1}^*, U_{2,1}^*\right)\right\|_\infty - \left\|\left(U_{3,1}^*, U_{4,1}^*\right)\right\|_\infty\right) \ge T; \quad (14)$$

$$L1_2: (-1)^b \cdot \left(\left\|U_{2,1}^*\right\|_1 - \left\|U_{3,1}^*\right\|_1\right) \ge T;$$

$$L2_2: (-1)^b \cdot \left(\left\|U_{2,1}^*\right\|_2 - \left\|U_{3,1}^*\right\|_2\right) \ge T.$$

For each embedding rule there is the same additional normalization constraint and the same goal function to minimize distortions (that is quite simple thanks to the proposed orthogonal matrix):

$$\left\|\left(U_{1,1}^*, U_{2,1}^*, U_{3,1}^*, U_{4,1}^*\right)\right\|_2 = 1$$
$$\sum_{i=1}^{4}\left(U_{i,1}^* - U_{i,1}\right)^2 \to min \quad (15)$$

3.3 Watermarking Procedure

After embedding is done the resulting matrix U^* should be composed with S^* and V^T which produces watermarked image fragment I^*. However, it is necessary to notice that I^* contains real-valued pixels instead of integers. There are many possible kinds of truncation and each kind distorts orthogonal matrix U^*, but, for example, simple round operation is quite negligible to retrieve a bit for some reasonable T (0.02 works well for all the embedding rules). A diagram of watermark embedding is shown on Figure 1.

As it follows from the diagram the least distorted watermarked fragments are chosen in order to replace the corresponding original fragments of the image. This is thanks to availability of different orthogonal matrices in the set used for the approximation. It is necessary to notice that in the current realization we utilized constant threshold for all the blocks, but threshold adaptation can be done in the future more easily (at once, non-iteratively) compared to (Tehrani, 2010) as distortion in our method depends only on the amplitude of a vector added to the first column of U.

To extract a watermark from the watermarked image it is required to know the key and the rule. However in contrast to embedding the extraction threshold for each rule is zero. The extraction diagram is given on Figure 2.

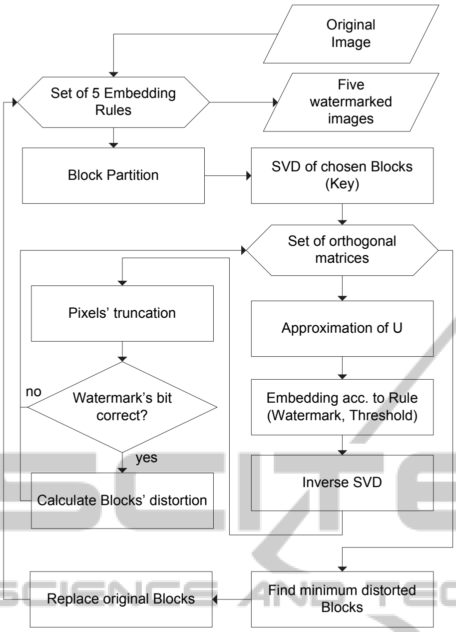


Figure 1: Watermark embedding diagram.

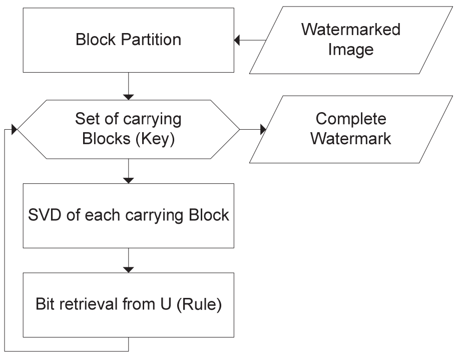


Figure 2: Watermark extraction diagram.

In our realization we also avoided embedding area to be limited only by blocks with greater complexity as defined in (Chang, 2005), (Tehrani, 2010), because due to some kind of distortion complexity (namely the number of non-zero singular values per block) could change and the person extracting a watermark could mismatch a key on different set. Another reason is that such a set has different size for different images which forces to use synchronized PRNG (Pseudorandom Number Generator, not steady key as we use) between embedder and extractor which is impractical.

4 EXPERIMENTAL RESULTS

In order to confirm the improvements of the proposed watermarking method some experiments took place. Each result has been compared with the result provided by the method described in (Chang, 2005) under the same circumstances. Original images, watermarking key and watermark were absolutely identical. We tried to adjust parameters so that Peak Signal to Noise Ratios (PSNRs) between each original image and the corresponding watermarked one were very close for both methods. There were four kinds of distortions used in the experiment: white Gaussian noise, speckle noise, "salt&pepper" and Jpeg compression.

Three grayscale host images with dimension 512x512 and bitdepth 8 bit were used for watermark embedding. Those images appear to be tested quite widely in papers related to image processing and are namely: livingroom.tif, mandril.tif and cameraman.tif (Figure 3-5). The choice of images for watermarking could be explained in a way that we tried to compare a performance of the proposed method on images with different amount of fine details. Here image livingroom.tif contains some areas with fine details, mandril.tif has a lot of fine details and cameraman.tif contains few details while having quite large areas with almost constant background.

The watermark for all our tests is the same and is 1024 bit long. For the better visual demonstration of each method's robustness it has been prepared in a form of square binary 32x32 image that depicts Canadian maple leaf. Each bit of the watermark has been embedded according to the same key (generated randomly) for all the images. The key defines 4x4 image fragments used for watermarking and is 16384 bit long. Extraction is done using the same key. Without distortions extraction of the watermark is absolutely correct for all the methods and images.

Taking into account that different rules were used for embedding in our method and the approximation had been done previously comparison with the method proposed in (Chang, 2005) is more complex. The only parameter influencing robustness in that method is a threshold, but embedding with the same threshold has different impact on an image when both methods are used. Therefore, the threshold for the method proposed in (Chang, 2005) has been adjusted after embedding by our method is done in a way that each in a pair of the corresponding watermarked images has the same (or very similar) PSNR.

Figure 3: Original grayscale image livingroom.tif.

Figure 4: Original grayscale image mandril.tif.

Figure 5: Original grayscale image cameraman.tif.

Four models of distortions applied to the watermarked images in our experiment could be split in two types according to the noise nature: additive and non-additive. Distortions with additive noise are namely Gaussian and speckle. Before applying distortions to watermarked images their pixel values were scaled to match interval [0, 1]. The mean for Gaussian is 0 and the variance shown in tables is 0.0006. Speckle noise adds, to each pixel $p_{i,j}$, the term $x \cdot p_{i,j}$ where x is distributed uniformly with mean 0 and variance 0.001. Distortions utilizing non-additive noise types are “salt & pepper” and lossy jpeg-compression. In our experiments we have applied 3% “salt & pepper” and 75 image quality for jpeg (Matlab realization).

An extraction with the key has been done afterwards. To compare the results we used the value 1-BER (Bit Error Rate) which indicates the fraction of correctly extracted bits of a watermark. We have placed the values 1-BER calculated according to each method, embedding rule and distortion type in separate table for each image (Tables 1-3). Each result has been averaged among 100 runs for all kinds of distortions except jpeg (as it is straightforward and does not contain random component). For better comparability each row with results from our method was neighbored to a row containing results with similar PSNR from method (Chang, 2005). For every pair of rows better indicator of robustness toward particular distortion is bolded.

Table 1: Results of watermark extraction for livingroom.tif.

Method, Rule	Gaussian, 0.0006	Speckle, 0.001	Salt & pepper, 0.03	Jpeg, 75
$L1_4$, 46.13dB	0.9325	0.9823	0.8451	**0.9844**
Chang,46.02dB	**0.9737**	**0.9997**	**0.8986**	0.9170
$L2_4$, 49.68dB	**0.8581**	0.9288	0.8333	**0.9268**
Chang,49.60dB	0.8571	**0.9464**	**0.8952**	0.7324
$L\infty_4$, 49.93dB	**0.8797**	**0.9602**	0.8805	**0.9092**
Chang,49.83dB	0.8410	0.9326	**0.8967**	0.7227
$L1_2$, 50.22 dB	**0.8833**	**0.9660**	**0.8954**	**0.8076**
Chang,50.22dB	0.8063	0.8961	0.8950	0.6865
$L2_2$, 50.22 dB	**0.8847**	**0.9662**	**0.8975**	**0.8066**
Chang,50.22dB	0.8063	0.8961	0.8950	0.6865

Table 2: Results of watermark extraction for mandril.tif.

Method, Rule	Gaussian, 0.0006	Speckle, 0.001	Salt & pepper, 0.03	Jpeg, 75
$L1_4$, 42.37dB	0.9681	0.9902	0.8690	**0.9961**
Chang,42.29dB	**0.9976**	**1.0000**	**0.9070**	0.9775
$L2_4$, 46.12dB	0.9026	0.9469	0.8539	**0.9297**
Chang,46.11dB	**0.9648**	**0.9988**	**0.8988**	0.8174
$L\infty_4$, 46.70dB	0.9138	0.9685	0.8837	**0.8652**
Chang,46.65dB	**0.9492**	**0.9949**	**0.8981**	0.7822
$L1_2$, 47.55dB	**0.9099**	0.9715	**0.9000**	**0.8057**
Chang,47.54dB	0.9060	**0.9736**	0.8979	0.7236
$L2_2$, 47.54dB	**0.9111**	0.9716	0.8978	**0.8076**
Chang,47.54dB	0.9060	**0.9736**	**0.8979**	0.7236

Table 3: Results of watermark extraction for cameraman.tif.

Method, Rule	Gaussian, 0.0006	Speckle, 0.001	Salt & pepper, 0.03	Jpeg, 75
$L1_4$, 45.70dB	0.8908	0.9745	0.8322	**0.9336**
Chang,45.70dB	**0.9153**	**0.9932**	**0.8918**	0.8125
$L2_4$, 50.89dB	**0.8123**	**0.8933**	0.8104	**0.8926**
Chang,50.82dB	0.7927	0.8876	**0.8471**	0.6094
$L\infty_4$, 51.06dB	**0.8419**	**0.9327**	**0.8667**	**0.8467**
Chang,51.05dB	0.7808	0.8712	0.8410	0.5840
$L1_2$, 52.32dB	**0.8377**	**0.9338**	**0.8591**	**0.7227**
Chang,52.30dB	0.6716	0.7365	0.8317	0.4922
$L2_2$, 52.31dB	**0.8419**	**0.9348**	**0.8603**	**0.7217**
Chang,52.30dB	0.6716	0.7365	0.8317	0.4922

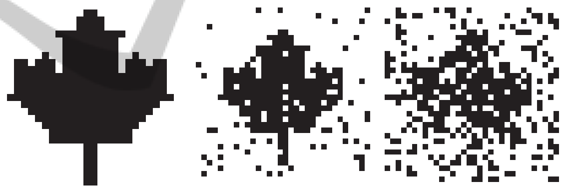
Images watermarked by the proposed method are depicted in Figures 6-8. The rule $L2_4$ has been used for this particular demonstration and PSNRs are 49.68 dB, 46.12 dB and 50.89 dB for livingroom.tif, mandril.tif and cameraman.tif respectively.

Figure 6: Watermarked grayscale image livingroom.tif.

Figure 7: Watermarked grayscale image mandril.tif.

Figure 8: Watermarked grayscale image cameraman.tif.

The threshold for the method proposed in (Chang, 2005) has been adjusted so that very similar PSNR has been achieved for each watermarked image. Compression according to jpeg standard has been done then. The watermarks extracted from the watermarked image livingroom.tif by both methods are shown together with the original watermark extracted from non-distorted watermarked image (Figure 9).



(a) (b) (c)

Figure 9: Original and distorted by jpeg compression watermarks.

The demonstrated binary images represent watermarks extracted with rates 1 (Figure 9. (a), both methods, no distortion), 0.9268 (Figure 9. (b), our method, jpeg 75), 0.7324 (Figure 9. (c), method (Chang, 2005), jpeg 75).

5 DISCUSSION

Comparing the rate of correct watermark extraction for our method and the method proposed in (Chang, 2005) and further developed in (Tehrani, 2010) we can state the following. Robustness demonstrated by our method against jpeg attack is much better than those demonstrated by (Chang, 2005). This is true for all the embedding rules, but to be said separately rule $L2_4$ provides the greatest improvement for all the trials with jpeg-compression: it is about 27%

better on livingroom.tif, about 14% better on mandril.tif and more than 46% better on cameraman.tif.

For other types of distortions including Gaussian, speckle, "salt&pepper" noises rules $L1_2$ and $L2_2$ performed better than others: about 10% outperform (Chang, 2005) for Gaussian on livingroom.tif, just 1% better than (Chang, 2005) for Gaussian on mandril.tif, but 27% better than (Chang, 2005) for speckle on cameraman.tif. There was no considerable advantage found for "salt&pepper" noise for any rule. However rules $L1_4$ and $L2_4$ usually perform worse under conditions with Gaussian, speckle, and "salt&pepper" noises. The rule $L\infty_4$ has considerable advantage on jpeg which is close to the advantage $L2_4$ has and under conditions with Gaussian, speckle, and "salt&pepper" noises in some cases performs several percent better than (Chang, 2005) (livingroom.tif and cameraman.tif). The highest achievement for rule $L1_4$ is to be 15% better toward (Chang, 2005) under jpeg-attack for cameraman.tif, but the gaps in trials with Gaussian, speckle, and "salt&pepper" noises are sometimes too high, so, it should probably be rejected from future experiments.

It is possible to issue a short guidance for end-user that reflects better flexibility of proposed method utilizing different rules: embedding rules $L1_2$ and $L2_2$ should be used if there are comparable chances for each kind of tested distortions to occur; rule $L\infty_4$ is better to be used when chances of jpeg compression are higher; we recommend to use rule $L2_4$ in case the only kind of possible distortion is jpeg.

The threshold used in all our embedding rules was the same. On the other hand, PSNRs of the watermarked images are quite high. So, in the future we would like to experiment with different values of the threshold (probably greater) and also apply adaptation for each block as it is proposed in (Tehrani, 2010). Another direction we might wish to explore is an embedding in U matrix of the blocks of greater size, but this requires a different model of orthogonal matrix to be used for approximation.

6 CONCLUSIONS

The watermarking method operating on U-domain of SVD transform was proposed. Its robustness is better than those for the method proposed in (Chang, 2005). The improvements are due to optimizations done on two stages of embedding.

The first stage serves for the approximation of U matrix of transformed 4x4 image blocks. The approximation was done according to the proposed model that describes orthogonal matrix analytically. This procedure allows to preserve orthogonality of U matrix after watermark bit is embedded. Orthogonality of U-matrix improves extraction rate.

The second stage represents an embedding according to one of five proposed embedding rules. Each of the embedding rules has its own trade-off between robustness and transparency which allows to choose the best rule for particular application. A minimization of embedding distortions was done for each rule during embedding which reduces degradation of original image.

Several kinds of attacks were applied to test robustness. It was experimentally confirmed that for each kind of attack there is a different embedding rule which is more preferable than the others. However, watermarking according to each of the proposed embedding rules outperforms the method proposed in (Chang, 2005) under condition of JPEG-attack.

ACKNOWLEDGEMENTS

The first author is thankful to Tampere Program in Information Science and Engineering for the support.

REFERENCES

Altun, O., Sharma, G., Celik, M., Bocko, M., 2006. A Set Theoretic Framework for Watermarking and Its Application to Semifragile Tamper Detection. *IEEE Transactions on Information Forensics and Security*, vol.1, no.4, 479-492.

Barni, M., Bartolini, F., Cappellini, V., Piva, A., 1997. Robust watermarking of still images for copyright protection. In *Proceedings of 13th International Conference on Digital Signal Processing Proceedings*, IEEE, Piscataway, NJ, USA, vol.2, 499-502.

Chang, C., Tsai, P., Lin, C., 2005. SVD-based digital image watermarking scheme. *Pattern Recognition Letters*, 26, 1577–1586.

Cox, I., Miller, M., Bloom, J., Fridrich, J., Kalker, T., 2007. *Digital Watermarking and Steganography*, Morgan Kaufmann Publishers Inc.. San Francisco, CA, USA, 2nd edition.

Dharwadkar, N.V., Amberker, B. B., Gorai, A., 2011. Non-blind watermarking scheme for color images in RGB space using DWT-SVD. In *Proceedings of ICCSP'11, International Conference on*

Communications and Signal Processing. IEEE, Piscataway, NJ, USA, 489-493.

Fridrich, J., 2002. Security of fragile authentication watermarks with localization. *Proceedings of SPIE 4675, Security and Watermarking of Multimedia Contents IV*, 4675, Vol. 4675, 691-700.

Fullea, E., Martinez, J. M., 2001. Robust digital image watermarking using DWT, DFT and quality based average. In *Proceedings of MULTIMEDIA'01, 9th International Conference on Multimedia.* ACM, New York, NY, USA, 489-491.

Ganic, E., Eskicioglu, A. M., 2004. Robust DWT-SVD domain image watermarking: embedding data in all frequencies. In *Proceedings of MM&Sec'04, Workshop on Multimedia and security.* ACM, New York, NY, USA, 166-174.

Lin, S. D., Chen, C. F., 2000. A robust DCT-based watermarking for copyright protection. *IEEE Transactions on Consumer Electronics*, 46, 415-421.

Manjunath, M., Siddappaji, S., 2012. A new robust semi blind watermarking using block DCT and SVD. In *Proceedings of ICACCCT'12, International Conference on Advanced Communication Control and Computing Technologies.* IEEE, Piscataway, NJ, USA, 193-197.

Modaghegh, H., Khosravi, R. H., Akbarzadeh, T., 2009. A new adjustable blind watermarking based on GA and SVD. In *Proceedings of IIT '09, International Conference on Innovations in Information Technology.* IEEE, Piscataway, NJ, USA, 6-10.

Pei S. C., Zeng Y. C., 2006. Tamper proofing and attack identification of corrupted image by using semi-fragile multiple-watermarking algorithm. In *Proceedings of the ASIACCS'06, Symposium on Information, computer and communications security.* ACM, New York, NY, USA, 166-174.

Quan, L., Qingsong, A., 2004. A combination of DCT-based and SVD-based watermarking scheme. In *Proceedings of ICSP'04, 7th International Conference on Signal Processing.* IEEE, Piscataway, NJ, USA, vol.1, 873- 876.

Singh, P., Agarwal, S., 2012. A region specific robust watermarking scheme based on singular value decomposition. In *Proceedings of SIN'12, 5th International Conference on Security of Information and Networks.* ACM, New York, NY, USA, 117-123.

Sun, R., Sun, H., Yao, T., 2002. A SVD- and quantization based semi-fragile watermarking technique for image authentication. In *Proceedings of 6th International Conference on Signal Processing.* IEEE, Piscataway, NJ, USA, vol.2, 1592- 1595.

Tehrani, I.O., Ibrahim, S., 2010. An enhanced SVD based watermarking using U matrix. In *Proceedings of ICCIT'10, 5th International Conference on Computer Sciences and Convergence Information Technology.* IEEE, Piscataway, NJ, USA, 627-631.

Xiao, J., Wang, Y., 2008. Toward a Better Understanding of DCT Coefficients in Watermarking. In *Proceedings of PACIIA'08, Pacific-Asia Workshop on Computational Intelligence and Industrial Application.* IEEE, Piscataway, NJ, USA, vol.2, 206-209.

Yongdong, W., 2005. On the security of an SVD-based ownership watermarking. *IEEE Transactions on Multimedia*, vol.7, no.4, 624- 627.