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# ROBUSTNESS OF THE SD WATERMARKING ALGORITHM IN IS MAPPING USING COMB FILTERING

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**Abstract**

*In this paper, robustness analysis of SD watermarking algorithm in IS mapping using COMB filter has been performed. The first part of the paper describes SD algorithm for inserting and extracting a watermark into an image. After that, conversion of the image has been performed. Converted image with inserted watermark into audio signal was filtered with COMB filtering. The second part of the paper presents an experiment in which robustness of the Schur algorithm in relation to COMB filtering has been tested. The COMB filter has been realized with scaling factor α and the delay length K. The obtained results were analyzed using objective (MSE and SSIM) and subjective (visual quality) quality measures.*

**Keywords:** keywords, keywords, keywords, keywords, keywords, keywords, keywords.

## INTRODUCTION

The rapid development of modern information and communication technologies has enabled a fast and intensive exchange of multimedia content. Also, the intensive development of software packages enables easy and fast downloading, editing of audio contents. However, this situation also affects malicious users, which leads to problems related to copyright protection. [1] - [3]. In order to solve the problem of copyright protection and proving the ownership of multimedia content, the principle of inserting hidden data is used. Inserting hidden digital data is called watermarking [4], [5]. The basic features of a digital watermark are insensitivity, robustness, capacity, non-inversibility and the ability to provide secure proof of ownership. [6]. A watermark can be: a) visible and b) invisible. An invisible watermark is inserted invisibly into another image so that it does not distort the visual characteristics of the image and can be extracted later for the purpose of proving copyright [2]. Many complex transformations are used to insert a watermark into an image, such as DCT [3], [7] (**engl**. *Discrete Cosinuse Transform*), DWT [6], [8] (**engl**. *Discrete Wavelet Transform*), SVD transformation [2], [7], [8] (**engl**. *Singular Value Decomposition*) and Schur decomposition (**engl.** *Schur Decomposition,* SD) [9], [10].

During digital processing, it is possible to translate the sound into an image for the purpose of visualization and vice versa, to translate the image into a sound [11]-[14]. The technique of converting an image into a sound is called image to sound (IS) mapping (*engl.* **I**mage to **S**ound mapping) [15]-[17], [18]. There are many techniques of converting the image into the sound [19]-[21].

The authors of this paper came up with the idea to test the algorithm for inserting a digital watermark so that after inserting the watermark, the image will be IS mapped in order to obtain an audio signal. The SD watermarking algorithm based on Schur decomposition was used to insert the watermark into the image. [9]. A Comb filter was applied over the audio signal, after which the audio signal was converted by an inverse method into an image from which a digital watermark was extracted. The robustness of the SD algorithm was tested by objective MSE and SSIM, subjective (visual quality testing) quality measures.

The paper is organized as follows: SD algorithm for insertion and extraction of digital watermark and Comb filter are presented in section II. Section III describes the experiment and presents the results. The conclusion is given in section IV.

## ALGORITHMS

### *A.* Shur decomposition

Schur decomposition applied to matrix *A* as a results returns two matrices, matrix *U* and *D*:

$$A = U \times D \times U', \quad (1)$$

where *U* is a unitary matrix, *U'* is a transposed matrix, and *D* is an upper triangular matrix. Two significant characteristics of the unitary matrix *U* that refer to the elements of the first column are: a) all elements are of the same sign and b) their values differ slightly [9]. Analysis of a large number of images and their Schur matrices in the transformation of blocks dimensions $4 \times 4$ showed that the strongest correlation between the elements $u_{21}$ and $u_{31}$ [9] therefore inserting of the watermark could be performed by modification of these elements.

### *B.* SD algorithm

The SD algorithm for watermark insertion, proposed in [9], is based on Schur decomposition and is performed in the following steps:

**Input**: original image $A_{M\times N}$, Binary watermark $W_{\mathrm{Mz}\times\mathrm{Nz}}$, block dimension $M_b \times N_b$.

**Output**: Watermarked image $A_w$.

*Step 1:* The dividing the original matrix *A* dimensions $X\times Y$ is performed on blocks $H_{Mb\times Nb}$, where $X = \lceil M / M_b \rceil$ and $Y = \lceil N / N_b \rceil$.

*Step 2*: Applying the Schur decomposition over blocks *H*:

$$H_{i,j} = U_{i,j} \times D_{i,j} \times U_{i,j}^T, \quad (2)$$

where *U* represent unitary matrix, *D* uper triangular matrix and $1 \le i \le \lceil M / M_b \rceil$ and $1 \le j \le \lceil N / N_b \rceil$.

*Step 3:* Elements $u_{2,1}$ and $u_{3,1}$ of each block of matrix *U* are modified to obtain a modified block $U'$ in accordance with the information of inserted binary watermark *W*.

Watermark insertion is performed in accordance with the (3) and (4). The binary watermark *W* is inserted by a modification made between the second element ($u_{2,1}$) and the third element ($u_{3,1}$) in the first column:

$$w_{i,j} = 1, \begin{cases} u'_{2,1} = sign(u_{2,1}) * (U_{avg} + T/2) \\ u'_{3,1} = sign(u_{3,1}) * (U_{avg} - T/2) \end{cases}, \quad (3)$$

$$w_{i,j} = 0, \begin{cases} u'_{2,1} = sign(u_{2,1}) * (U_{avg} - T/2) \\ u'_{3,1} = sign(u_{3,1}) * (U_{avg} + T/2) \end{cases}, \quad (4)$$

where *sign(x)* represent the sign of *x* and $U_{avg} = (|u_{2,1}| + |u_{3,1}|)/2$, $|x|$ represent absolutely value of *x*.

*Step 4*: Reconstruction of the block with inserted watermark:

$$H'_{i,j} = U_{i,j} \times D'_{i,j} \times U_{i,j}^T, \quad (5)$$

*Step 5*: Creating the image with the watermark $A_w$ from the blocks *H'*.

SD algorithm for watermark extraction is performed in the following steps:

**Input**: $A_w$- Watermarked image, $M_b\times N_b$ - block dimension.

**Output**: $W'_{Mz\times Nz}$ - reconstructed binary watermark.

*Step 1:* Dividing of matrix $A_w$ dimension $X\times Y$ on blocks $H'_{Mb\times Nb}$ is performed, where $X = \lceil M / M_b \rceil$ and $Y = \lceil N / N_b \rceil$.

*Step 2*: Applying the Schur decomposition on the blocks *H'*:

$$H'_{i,j} = U'_{i,j} \times D'_{i,j} \times (U'_{i,j})^T, \quad (6)$$

where *U'* represent unitary matrix, *D'* represent upper triangular matrix and $1 \le i \le \lceil M / M_b \rceil$ and $1 \le j \le \lceil N / N_b \rceil$.

*Step 3*: Watermark bit extraction *bw'* from the matrix *D'*:

$$w'_{i,j} = \begin{cases} 0, & if \quad u'_{2,1} > u'_{3,1} \\ 1, & if \quad u'_{2,1} \le u'_{3,1} \end{cases}, \quad (7)$$

*Step 4*: Creating the watermark *W'* from od extracted bits $w_{i,j}'$.

The effect of the Comb filter was realized by applying the filter shown in Fig. 1 [14].

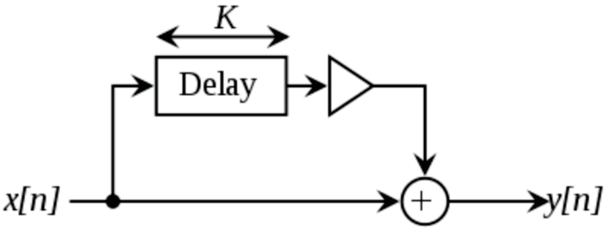



***Fig. 1.*** *Block diagram of the Comb filter*

## EXPERIMENTAL RESULTS AND ANALYZE

### *A.* Experiment

For the purpose of testing the influence of Comb filter filtering on the robustness of the extracted digital watermark in IS mapping, the following experiment was performed:

**Input**: $X$- Image Cameraman, $W$-digital watermark, $T$ – watermark inserting coefficient, $M_b \times N_b$. block dimensions.

**Output**: $W_e$ – extracted digital watermark.

*Step 1:* Using the SD algorithm, a digital watermark was inserted into the image.

*Step 2:* The image with the watermark is transformed into the audio signal, $x_w$.

*Step 3:* A Comb filter was applied to the audio signal with the inserted watermark $x_w$, with with a scaling factor $\alpha$ ($0 \le \alpha \le 1$) and the delayed signal, delay length $K$, varied in range ($1 \le K \le 20$).

*Step 4*: From the signal, over which the Comb filter was applied, $y_n$, using the algorithm shown in section II the audio signal is transformed into an image $A_{WN}$.

*Step 5*: From the image $A_{WN}$ a digital watermark has been extracted.

*Step 6*: A comparative analysis of the extracted digital watermark was performed $W_{eN}$ with original watermark $W$ by applying objective quality measures.

For an objective quality measurement, the mean square error was applied:

$$MSE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(W(i,j) - W_{eh}(i,j)\right)^2}{M \times N}, \quad (8)$$

and Structural symilarity index:

$$SSIM = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(W(i,j) \cdot W_{eh}(i,j)\right)}{\sqrt{\sum_{j=1}^{N}\left(W(i,j)\right)^2} \cdot \sqrt{\sum_{j=1}^{N}\left(W_{eh}(i,j)\right)^2}} \quad (9)$$

The Comb filter is described by the difference equation:

$$y(n) = x(n) + \alpha \cdot x(n-K) \quad (10)$$

where $\alpha$ ($0 \le \alpha \le 1$) is a scaling factor applied to the delayed signal, $K$ is the delay length (measured in samples, $1 \le K \le 20$).

The $z$ transform of of the equation (10) yields:

$$Y(z) = \left(1 + \alpha z^{-K}\right) \cdot X(z) \quad (11)$$

The transfer function is defined as:

$$H(z) = \frac{Y(z)}{X(z)} = 1 + \alpha z^{-K} = \frac{z^K + \alpha}{z^K} \quad (12)$$

Amplitude characteristic |H| is calculated in the $z$-plane on the circle $r = 1$.

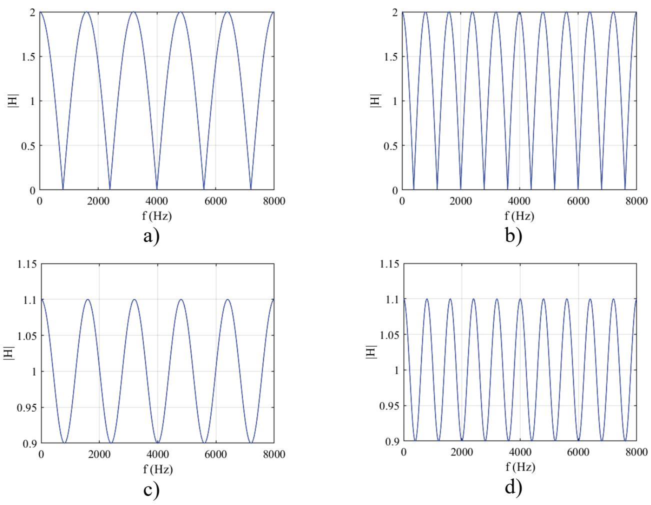



***Fig. 2.*** *Amplitude characteristics of Comb filter for: a) K = 10 and α = 1, b) K = 20 and α = 1, c) K = 10 and α = 0.1 and d) K = 20 and α = 0.1.*

In the experiment image Cameraman dimension 256 × 256 is used (Figure 3.a) in which a digital watermark dimension 64 × 64 was inserted. Watermark is specially generated for the purposes of the experiment (Figure 3.b). The watermark was generated by randomly generating 50% of black and 50% of white pixels. The image is translated into the sound. The sampling frequency of the obtained audio signal is $F_s = 16$ kHz. Filtering with a Comb filter was performed with a scaling factor $\alpha$ ($0 \le \alpha \le 1$) and the delayed signal, delay length $K$, varied in range ($1 \le K \le 20$). The watermark was inserted using the SD algorithm for insertion and extraction of the watermark, with the coefficient insertion $T = 0.01$.

Amplitude characteristics of Comb filter is presented in figure 2: a) $K = 10$ and $\alpha = 1$, b) $K = 20$ and $\alpha = 1$, c) $K = 10$ and $\alpha = 0.1$ and d) $K = 20$ and $\alpha = 0.1$.

a) b)

***Fig. 3.*** *Images used in the paper: a) Lena, and b) Watermark.*

### *B.* Results

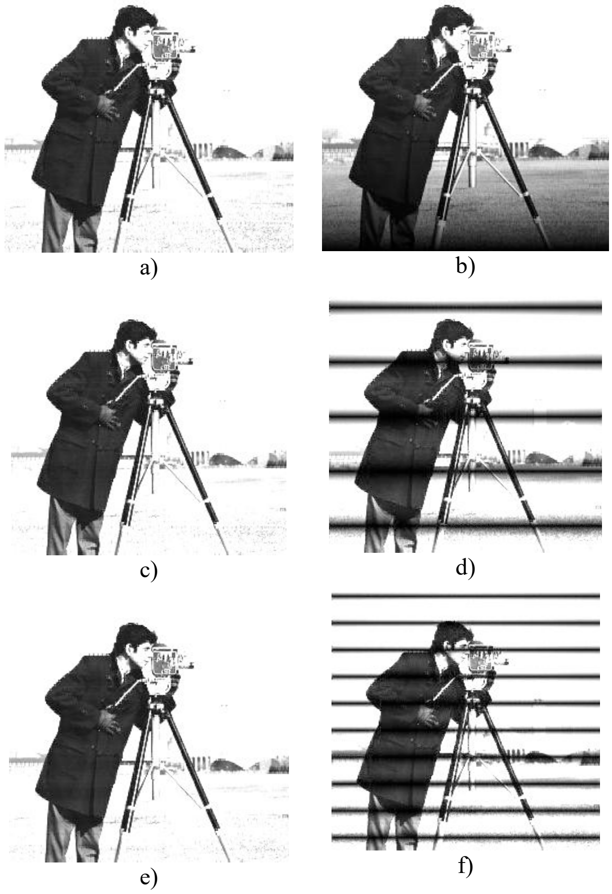
Realization of experiment resulted with:

a) in fig. 4. the appearance of the image obtained from the signal over which the Comb filter was applied, has been presented, with the scaling factor $\alpha$ and the delayed signal $K$: a) $K = 1$ and $\alpha = 0.1$, b) $K = 1$ and $\alpha = 1$, c) $K = 10$ and $\alpha = 0.1$, d) $K = 10$ and $\alpha = 1$, e) $K = 20$ and $\alpha = 0.1$ and f) $K = 20$ and $\alpha = 1$.

b) in fig. 5. the appearance of the extracted watermark from the signal over which the Comb filter was applied, has been presented, with the scaling factor $\alpha$ and the delayed signal $K$: a) $K = 1$ and $\alpha = 0.1$, b) $K = 1$ and $\alpha = 1$, c) $K = 10$ and $\alpha = 0.1$, d) $K = 10$ and $\alpha = 1$, e) $K = 20$ and $\alpha = 0.1$ and f) $K = 20$ and $\alpha = 1$.

c) in fig. 6. is presented MSE for extracted watermark (insertion factor $T = 0.01$), and varied the delay length $K$ ($1 \le K \le 20$), and averaged for scaling factor $\alpha$. In fig. 7. is presented MSE for extracted watermark (insertion factor $T = 0.01$), and varied the scaling factor $0 \le \alpha \le 1$, and averaged for Delay length is set on value $K$.

d) in fig. 8. is presented SSIM for extracted watermark (insertion factor $T = 0.01$), and varied the delay length $K$ ($1 \le K \le 20$), and averaged for scaling factor $\alpha$. In fig. 9. is presented SSIM for extracted watermark (insertion factor $T = 0.01$), and varied the scaling factor $0 \le \alpha \le 1$, and averaged for delay length is set on value $K$.



a) b) c) d) e) f)

***Fig. 4*** *Visual appearance of image after applying the Comb filter for: a) K = 1 and α = 0.1, b) K = 1 and α = 1, c) K = 10 and α = 0.1, d) K = 10 and α = 1, e) K = 20 and α = 0.1 and f) K = 20 and α = 1.*

a) b)

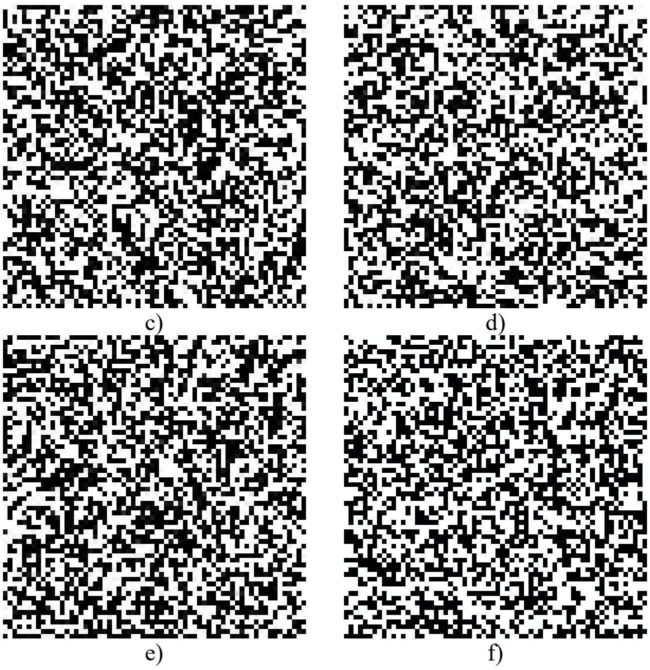



*Fig. 5.* *Visual appearance of extracted watermark* (*T* = *0.01*) *after applaing the Comb filter: : a)* *K* = 1 *and* α = 0.1, *b) K* = 1 *and* α = 1, c*) K* = 10 *and* α = 0.1, *d) K* = 10 *and* α = 1, *e) K* = 20 *and* α = 0.1 *and f) K* = 20 *and* α = 1.

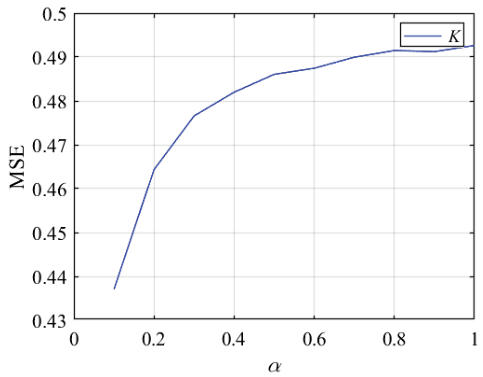



***Fig. 6.*** *Diagram of MSE for extracted watermark (T = 0.01), averged for the delay length K (1 ≤ K ≤ 20).*

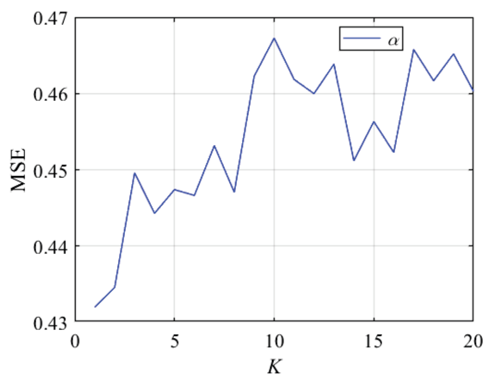



***Fig. 7.*** *Diagram of MSE for extracted watermark (T = 0.01), averged for scaling factor α (0 ≤* α *≤ 1).*

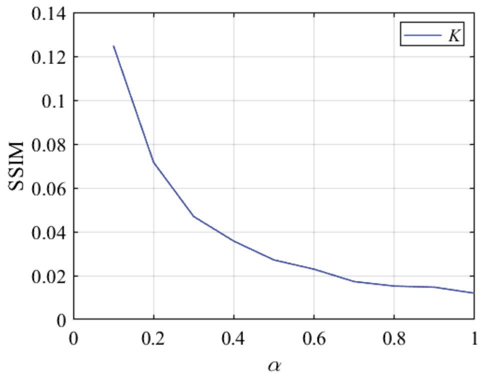



***Fig. 8.*** *Diagram of SSIM for extracted watermark (T = 0.01), averged for the delay length K* (1 ≤ *K* ≤ 20).

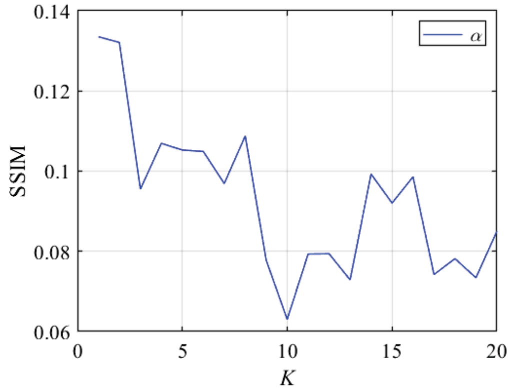



***Fig. 9.*** *Diagram of SSIM for extracted watermark* (*T* = *0.01*), *averged for scaling factor* α (0 ≤ α ≤ 1).

### *C.* Analyze of the results

Subjective comparative analysis of the visual quality of the extracted watermarks presented in fig. 5. (insertion coefficient *T* = 0.01) cannot show the significance of degradation of the extracted watermark.

Objective analysis was conducted based on the MSE results shown in fig.6. and fig.7., and SSIM shown in fig.8. and fig.9. The analysis of the results concludes that after applying the Comb filter to the audio signal, the quality of the extracted watermark is poorer for higher values of the delay length K. Higher values of scaling factor α causes higher values of MSE, extracted watermark is with lower quality. Based on the results (SSIM) shown in fig.8. and fig.9. it can be concluded that after applying the Comb filter to the audio signal the quality of the extracted watermark is poorer for higher values of the delay length *K*. Higher values of scaling factor α causes lower values of SSIM, extracted watermark is with lower quality.

## CONCLUSION

In this paper is analyzing the robustness of the SD watermarking algorithm in IS mapping, on the Comb (audio signal) filtering. Comb filter was performed with a scaling factor $\alpha$ ($0 \le \alpha \le 1$) and the delayed signal, delay length $K$, varied in range ($1 \le K \le 20$). The watermark was inserted using the SD algorithm for insertion and extraction of the watermark, with the insertion coefficient $T = 0.01$. After a detailed objective (MSE and SSIM) and subjective (visual quality) analysis of the extracted watermark, it was concluded that the quality of the extracted watermark is poorer for higher values of the delay length $K$. Higher values of scaling factor $\alpha$ causes higher values of MSE, extracted watermark is with lower quality. Higher values of scaling factor α causes lower values of SSIM, extracted watermark is with lower quality.

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