Robustness of the SD watermarking algorithm for γ-corrected images with superimposed Gaussian noise

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Abstract –**First part of the paper describes the algorithm for γ-correction, algorithm for superposition of Gaussian noise and the algorithm for inserting a watermark based on Schur decomposition (SD algorithm). In the second part of the paper, an experiment was described in which the insertion and extraction of the digital watermark in the image was performed. Gaussian noise is superposed to watermarked image, after which it is deformed by a change in contrast using an γ-correction algorithm. The γ coefficient is varied in range γ = 0.25 ÷ 4. A watermark is extracted from the γ-corrected image. The quality control of an extracted watermark was performed using objective quality measure-MSE, and a visual comparison of the extracted and original watermark.**

Keywords – **Schur decomposition, SD algorithm, γ-correction, Gaussian noise, watermark.**

I. Introduction

The widespread use of digital media makes it possible to manipulate the images. Image manipulation (filtering, contrast changes, re-scaling ...) are used to improve visual image quality [1]. The most widespread image manipulation known as γ-correction or γ-transformation is used to change the contrast of the image and is determined by a single parameter [2]. On other side manipulation with the images can lead to damages which are caused by noise. In the process of digital image processing (transmission, acquisition, equipment characteristic ...) images can be corrupted with Impulse noise and Gaussian (AWGN) noise [2], [3]. Salt and pepper replaces certain pixel images with random values. The AWGN, affects on the entire set of pixels of an image. AWGN noise afects pixels randomly between the minimum and the maximum value of the pixel [4], resulting in the fact that the image looks hazy and blurred. At small noise densities of AWGN, the image restoration can be satisfactorily corrected with gamma correction.

In the process of digital image processing, another very important feature is the protection of copyrights. Copyright protection is best done by invisible watermarks. An invisible watermark is inserted into the image in order not to destroy visual characteristics of the image and may be later extracted for the purpose of proving copyrights [5], [6]. The imperfection of invisible watermark is that they can be insufficiently robust and resistant to disturbances.

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The authors of this paper set the question: How does γ-correction affect an extracted watermark, from a noised (with AWGN) watermarked image? In order to obtain the answer, authors conducted an experiment in which: a) a good quality (GQ) image [7] was formed, b) watermark (with the SD algorithm [8], [9], [10]) in GQ image was inserted, c) Gaussian noise with SNR = [10:2:30] on the watermarked image was superimposed, d) watermarked image was deformed by contrast change using γ-correction (γ = 0.25 ÷ 4) [11], [12], and e) watermark was extracted and its quality checked. The quality of the extracted watermark was checked using objective measurements of the quality: Mean Square Error (MSE), as well as visual comparison of the extracted and original watermark.

The paper is organized in the following way. Section II describes: SD algorithm for inserting and extracting watermark and algorithms for γ-correction and superposition of Gaussian noise. Section III describes an experiment. Section IV presents results and analysis of the results. Section V is a conclusion.

II. Algorithms

The SD algorithm based on Schur decomposition [9], [13] was used for inserting a digital watermark. The algorithm is executed in the next steps:

Input: original image $A_{M\times N}$, binary watermark $W_{Mz\times Nz}$, block dimensions $M_b \times N_b$.

Output: watermarked image X_W.

Step 1: Original matrix is divided on $X \times Y$ blocks, $H_{Mb\times Nb}$, where $X = \lceil M / M_b \rceil$ and $Y = \lceil N / N_b \rceil$.

Step 2: Applying Schur decomposition on blocks H:

$$H_{i,j} = U_{i,j} \times D_{i,j} \times U_{i,j}^T , \tag{1}$$

where U is unitary matrix, D 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: The elements $u_{2,1}$ and $u_{3,1}$ in each block of matrix U are modified in order to obtain a modified block U', according to the information about the embedded binary watermark W. The insertion of the digital watermark is performed in accordance with the rule shown in (2) and (3), by modifying the elements $u_{2,1}$ and $u_{3,1}$:

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

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

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

Step 4: Reconstruction of the block with inserted watermark:

$$H'_{i,j} = U_{i,j} \times D'_{i,j} \times U^{T}_{i,j}, \tag{4}$$

Step 5: Forming watermarked image A_w from blocks H'.

SD algorithm for watermark extraction is performed in following steps:

Input: watermarked image A_w, blocks dimensions $M_b \times N_b$.

Output: Reconstructed binary watermark $W'_{Mz\times Nz}$.

Step 1: Matrix (A_w) dividing is performed on $X \times Y$ blocks, $H'_{Mb\times Nb}$, where $X = \lceil M / M_b \rceil$ and $Y = \lceil N / N_b \rceil$.

Step 2: Applying Schur decomposition on blocks H':

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

where U' denotes unitary matrix, D' 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: Extracting one bit, bw', of watermark from matrix D':

$$w'_{i,j} = \begin{cases} 0, & if \quad |u'_{2,1}| < |u'_{3,1}| \\ 1, & if \quad |u'_{2,1}| \ge |u'_{3,1}| \end{cases} \tag{6}$$

Step 4: Forming watermark W' from extracted bits $w_{i,j}'$.

Deforming image, by changing the contrast, using γ-correction by doing γ-transformation of an image, to the desired mean luminance value μ.

$$A_{\gamma} = A^{\gamma} . \tag{7}$$

where A denotes original image and A_γ denotes γ-corrected image.

Gaussian noise is superimposed to the image:

$$A_{N(i,j)} = A_{(i,j)} + \sigma * N . \tag{8}$$

where A-denotes original image and A_N-image with superimposed Gaussian noise, N- denotes Gaussian noise and σ-variance.

III. Experimental results and analysis

A. Experiment

For the purpose of testing the effect of γ-correction on the digital watermark inserted using SD algorithm, the following experiment is performed:

Step 1: On the original image A γ-correction is applied so as to obtain: a) $A_{0.5}$ - GQ image, (μ = 0.5); b) $A_{0.25}$ - darken image, (μ = 0.25); and c) $A_{0.75}$ - lighten image, (μ = 0.75).

Step 2: Image with the watermark A_w is obtained as it is in original image A, which is divided onto blocks $M_b \times N_b = 4 \times 4$, applying Schur decomposition inserted binary watermark W, dimensions $M_w \times N_w = 128 \times 128$, with insertion coefficient T. In every block one bit of the watermark is inserted.

Step 3: Gaussian noise (SNR=[10:2:30]) is superimposed to the image with inserted digital watermark $A_{\mu W}$,

Step 4: Watermarked image $A_{\mu W}$ is γ-corrected, with γ-coefficient varied in range 0.25 ÷ 4. The watermarked γ-corrected image is obtained $A^{\gamma}_{\mu W}$.

Step 5: Watermark W_e is extracted from γ-corrected image $A^{\gamma}_{\mu W}$.

As a quality measure of extracted watermark, a visual comparison of the extracted watermark and original watermark, and MSE are used:

$$MSE = \frac{\sum_{ij} \left(x_{ij} - y_{ij}\right)^2}{M \times N}, \tag{9}$$

where: x_{ij}, y_{ij}, i,j-the pixel of original and proceeded elements of the image, $M \times N$-dimensions of the image, d - maximal value of pixel.

Images Lena, Girl and Babon dimensions (512 × 512), fig. 1-a,b,c are used in experiment. As watermark is used image fig. 1-d dimension (128 × 128). The velues of coefficient insertion are varied, T = {0.0025, 0.005, 0.0075, 0.01, 0.015, 0.02, 0.025, 0.03}.

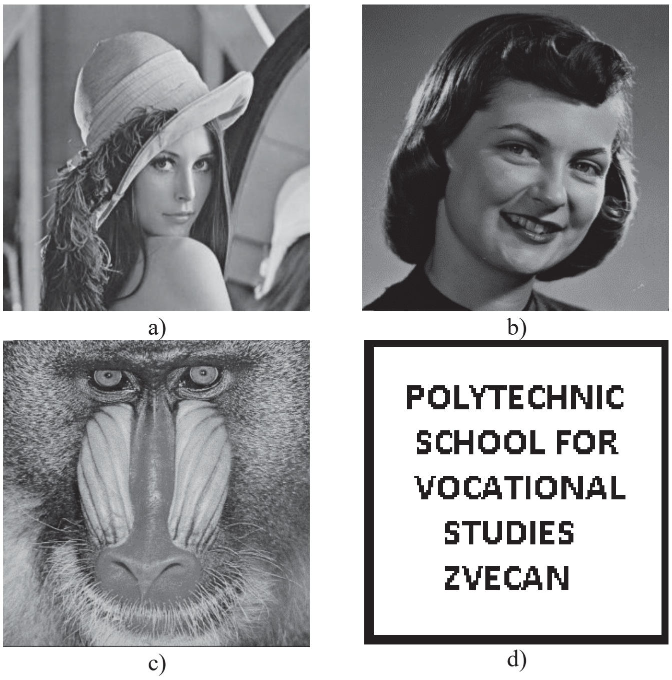


Fig. 1. Images used in the paper: a) Lena, b) Girl, c) Baboon and d) Watermark

B. Results

Appearance of the GQ image after watermark insertion (T = 0.01) and superimposed noise with SNR={12, 18, 24, 30} is shown in fig. 2.

Fig. 3 shows appearance of extracted watermark, from the image in which it is inserted with $T = 0.01$ (averaged for all values of γ-coefficient) and: a) $\mu = 0.25$ and $SNR = 18$ dB, b) $\mu = 0.25$ and $SNR = 24$ dB, c) $\mu = 0.5$ and $SNR = 18$ dB, d) $\mu = 0.5$ and $SNR = 24$ dB, e) $\mu = 0.75$ and $SNR = 18$ dB, f) $\mu = 0.75$ and $SNR = 24$ dB. Fig. 4. shows diagram for MSE, for watermark extracted from images, for different levels of luminance $\mu = \{0.25, 0.5, 0.75\}$, depending on SNR ($T = 0.01$). Fig. 5. shows diagram for MSE for extracted watermark depending on γ-coefficient (T=0.01, $\mu = 0.5$) for value of SNR={12, 18, 24, 30}. Fig. 6. shows diagram for MSE for extracted watermark depending on SNR, for three levels of insertion coefficient $T = \{0.0025, 0.01, 0.025\}$ (averaged for all values of γ-coefficient).

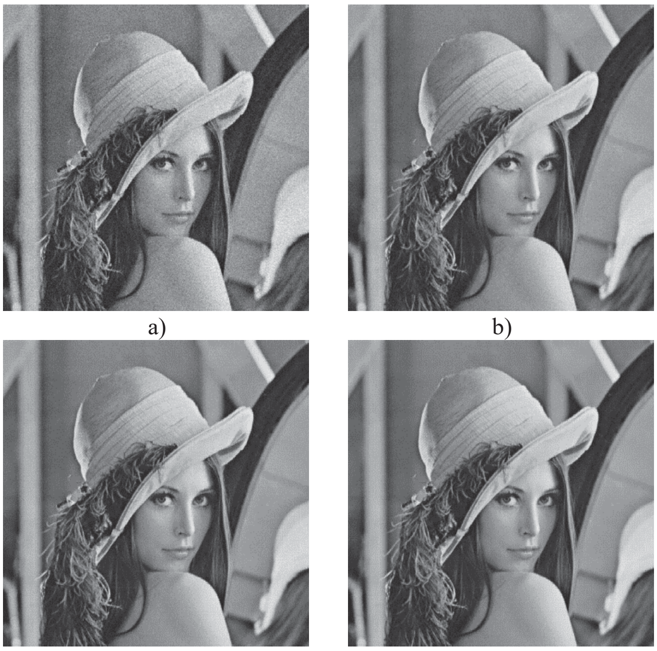
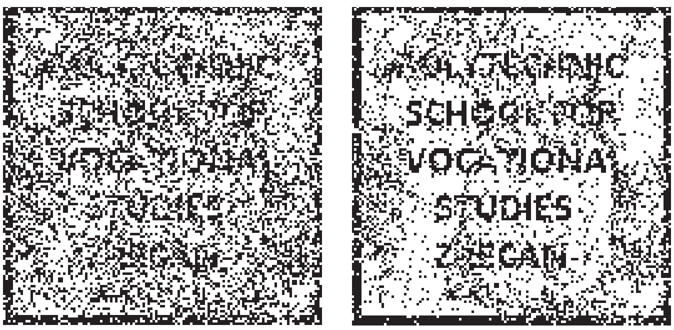


Fig. 2. Appearance of images after inserting digital watermark (in GQ image, $\mu = 0.5$ and T=0.01) and superimposing Gaussian noise with: a) $SNR = 12$ dB, b) SNR= 18 dB, c) $SNR = 24$ dB, and d) $SNR = 30$ dB.



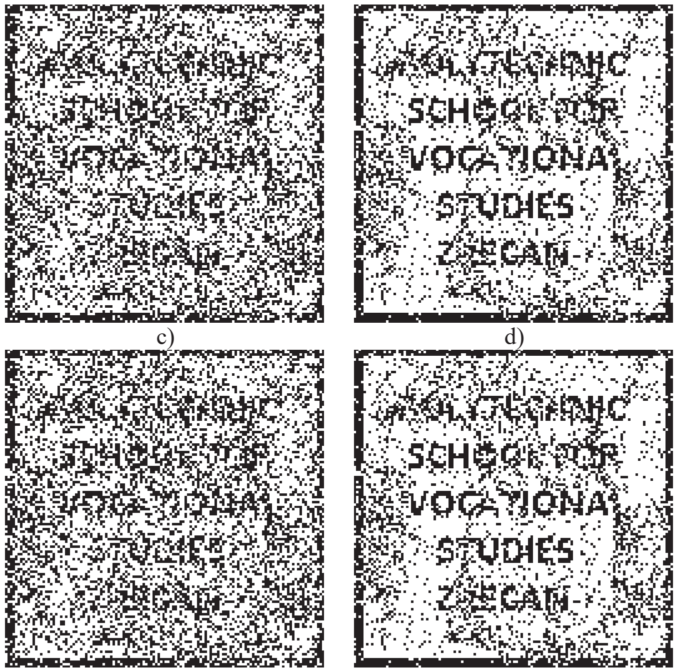


Fig. 3. Appearance of extracted watermark from image Lena (T = 0.01) for: a) $\mu = 0.25$ and $SNR = 18$ dB, b) $\mu = 0.25$ and $SNR = 24$ dB, c) $\mu = 0.5$ and $SNR = 18$ dB, d) $\mu = 0.5$ and $SNR = 24$ dB, e) $\mu = 0.75$ and $SNR = 18$ dB, f) $\mu = 0.75$ and $SNR = 24$ dB.

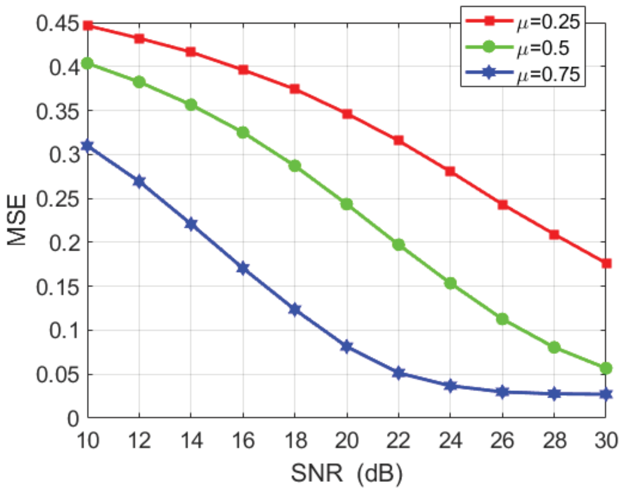


Fig. 4. The MSE of extracted watermark depending of value of SNR for different values of luminance μ ($T = 0.01$).

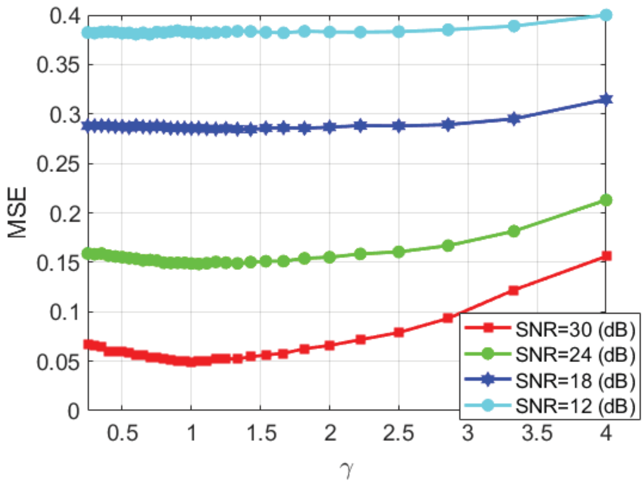


Fig. 5. The MSE of extracted watermark depending of γ-coefficient, for different values of *SNR* (μ=0.5, T = 0.01).

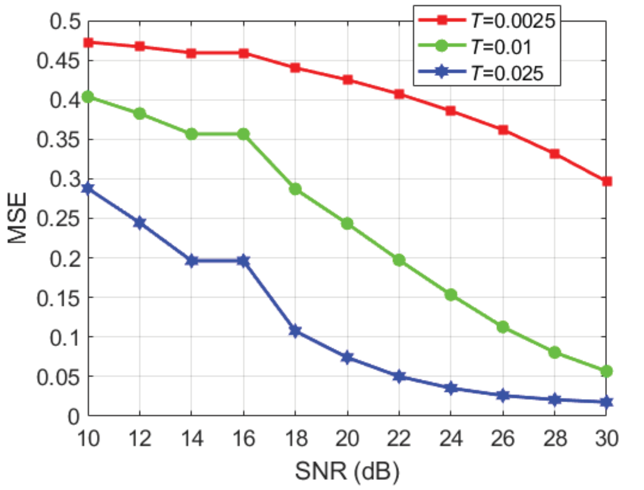


Fig. 6. The MSE of extracted watermark (averaged for all values of γ-coefficient) depending on inserting coefficiente T, (μ=0.5).

C. Analysis

Based on the results shown in fig. 3 and the diagrams shown in figs. 4 - 6. it can be concluded that:

a) The watermark extracted (inserted with T = 0.01), from image with luminance μ = 0.75 is with the best appearance. When value of SNR increases, the quality of extracted watermark rises. When ratio of the SNR = 30 dB, the extracted watermark is with the best quality. The extracted watermark is visible at SNR = 18 dB (Fig. 3);

b) The MSE of extracted watermark (inserted with T = 0.01) has the smallest image value with luminance μ = 0.75 (lighted image) (fig. 4.);

c) The MSE of extracted watermark (inserted with T = 0.01) has the smallest image value when *SNR* = 30 dB. The influence of γ-correction on the MSE extracted watermark is decreasing with decreasing of *SNR* value. For value *SNR* < 18 dB influence of γ-correction on the quality of extracted watermark is negligible (fig. 5.);

d) The MSE of extracted watermark proportionally decreases with increasing insertion coefficient T (fig. 6.).

IV. Conclusion

In this paper testing of influence of the γ-correction on the extracted digital watermark which is inserted in the image is performed, applying SD algorithm, to which Gaussian noise is superimposed. Based on the detailed analysis of the results obtained from the experiment it can be concluded that extracted watermark from the noised image (Gaussian noise) can be visible when value of SNR > 18 dB. Extracted digital watermark from the noised image (Gaussian noise) is with better visible appearance after extraction from image which is preprocessed, to be lighten, and luminance set on value μ = 0.75. With the increasing ratio of *SNR* quality of extracted watermark is getting more visible, and MSE is decreasing with increasing value of *SNR*. With the increase of insertion coefficient quality of extracted watermark is getting better and proportionally increases with increasing value of *SNR*. Based on the above stated it can be concluded that Gaussian noise with relatively small value of SNR significantly influences the quality of extracted watermark.

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