# DIGITAL VIDEO PROTECTION IN THE DWT-SVD DOMAIN USING SCRAMBLED WATERMARK BY GMSAT ALGORITHM

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***Keywords***: *DWT, GMSAT algorithm, H.264/AVC codec, SVD, Watermark.*

**Abstract: In this paper, the protection of video content from copying by embedding a scrambled watermark is considered. The watermark is scrambled by the GMSAT algorithm, and the insertion is performed by a reliable algorithm in the DWT-SVD domain of each frame. The video is encoded by the H.264/AVC encoder before it is uploaded on a Web server, while variable-quality watermarks are extracted on the client side from the decoded video. Using an algorithm for quality enhancement of the extracted watermark, the excellent SSIM index of 0.8956, and NC coefficient of 0.9852 was realized. The obtained results are in rank with the best one published. Experimental results justify the use of the shown video protection technique because it provides a higher quality of the extracted watermark compared to other insertion techniques.**

## 1. INTRODUCTION

Protecting the original multimedia content from copying and illegal distribution becomes a necessary activity before publishing them on the Web [1]. The use of standard cryptographic techniques does not provide a high level of security because one-time decrypted multimedia content on the client side can be copied and distributed illegally without permission. Also, additional time required for decrypting content, as well as possible retransmission of packets, can negatively affect the level of user satisfaction QoE (*Quality of Experience*) [2]. In practice, the concept based on the watermark embedding

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into a multimedia content is often used to protect multimedia content [3] – [11]. This concept requires that the embedded watermark stays permanently in the multimedia content. Since the watermark is never removed from the content, its insertion must not cause visible degradation of quality. On the other hand, in the process of the copyright protection, it is necessary to extract watermark with a satisfactory quality [12].

The compromise between the robustness of the watermark and the caused interference in the multimedia content can be realized by the corresponding value of the insertion factor. Higher insertion factor provides extraction of a higher quality watermark, but lower quality of protected video (and vice versa). The watermark can be considered of multimedia content, and in this way it shares the fate of the multimedia content itself. Attempting to remove the watermark from the video will have an effect on the quality of the multimedia content and on the quality of the watermark. In this paper, the protection of uncompressed video content by incorporating the same watermark into each video frame is considered. The watermark is encrypted before insertion because knowledge of watermark content can be compromising. Unlike algorithms where hybrid encryption techniques are used, this paper proposes the application of GMSAT (*Generalized MultiStage Arnold Transformation*) [13] which belong to the class of invertible 2D chaotic maps [14]. With the application of GMSAT, the cryptographic space of the watermark can be increased arbitrarily, thus increases the protection level.

The embedding lower resolution watermark causes less artifacts in the protected video content [15]. The proposed technique of embedding scrambled lower resolution watermark is based on the combination of DWT [16] (*Discrete Wavelet Transform*) and SVD (*Singular Value Decomposition*) [17]. SVD is a very popular technique for inserting a watermark because it ensures that small changes in singular values do not lead to significant image degradation. This feature, among other things, increases the SVD's resistance to malicious attacks. An inverse GMSAT [13] has been developed to obtain the original watermark from scrambled one. The second DWT level was used to match the resolutions for the application of a reliable SVD algorithm for inserting a watermark [17]. By inserting a scrambled watermark into all frames, a protected video content is obtained. Encoding of protected video is a standard compression process that is performed before exposing it on the Web. It is known that encoding ignores the details in the frames, but in return a high level of compression is obtained. From the viewpoint of watermark survival, encoding can be considered as an attack on the video itself. In this paper, the H.264/AVC encoder is used, which is characterized by a high degree of compression and good decoded video quality [18]. The consequences of coding and mathematical rounding are reflected in the variable quality of extracted watermarks. For the purpose of repairing the quality of the extracted watermark, enhancement correction algorithm [11] was applied.

Organization of the rest of the work is as follows. The second chapter presents the basics of used mathematical transformations. For the watermark encryption GMSAT is used - that can be classified in the 2D chaotic maps, while the special features of the SVD and DWT is used for watermark embedding. In the third chapter, reliable modified algorithms for the incorporation (extraction) of the watermark into (from) the protected video are presented. In the fourth chapter, the proposed algorithm was evaluated by extracting the watermark from encoded protected video by H.264/AVC encoder. The assessment of the extracted watermark quality was done by objective techniques based on the SSIM (Structural

SIMilarity) and NC (Normalized Correlation) coefficient. In the fifth chapter, appropriate conclusions were drawn on the basis of the performed research.

## 2. PRELIMINARIES

In this section, the basic characteristics of the used mathematical transformations will be briefly presented: GMSAT [13], DWT [19] and SVD [20].

### A. Generalized Multi-Stage Arnold Transformation - GMSAT

Although 2D pseudorandom images can be used as watermarks, the logo of proprietary companies is most often used. Before inserting, for security reasons, the contents of the logo should be made unrecognizable, which is done in this paper by scrambling. For scrambling watermark content, 1D sequences based on logical maps [12] can be applied, but in this paper 2D chaotic maps based on Arnold transformation are used. In previous works, the authors proposed MSAT (*Multi-Stage Arnold Transformation*) [11], [12] for scrambling the watermark content. By scrambling, the recognizable watermark reorganizes into an unrecognizable and seemingly random one. The basic idea of MSAT is the consecutive application of several different Arnold transformations *I* (called stages) to the watermark. Transformation parameters of the *i*-th stage $a_i$, $b_i$, and the number of consecutive iterations of the stage $k_i$ representing keys for encryption, and the period of each stage of Arnold transformation $T_i$ is additionally required for decryption phase. In MSAT, the dimension of square watermark *N* is equal in all stages. This paper uses GMSAT, which is an advanced version of MSAT. In GMSAT, a square watermark dimension is permitted, and the transformation area is additionally enlarged [13]. At each stage of this transformation, the value of the square watermark can be arbitrarily chosen, and it is recommended that $N_1 = N_I = N,\ N_{i-1} \geq N_i$. Each of the stages *i* can be described in 2D GMSAT by expressions (1) and (2):

$$\begin{bmatrix} x_{n+1} \\ y_{n+1} \end{bmatrix} = \left( \begin{bmatrix} 1 & b_i \\ a_i & a_i b_i + 1 \end{bmatrix} \begin{bmatrix} x_n \\ y_n \end{bmatrix} \right) mod N_i \tag{1}$$

$$N_i \leq N, i \in (1, 2, \dots I)$$

$$(x, y) \in (0,1, \dots, N_i - 1) \times (0,1, \dots, N_i - 1) \subset Z^2 \tag{2}$$

where $x_n$, $y_n$ and $x_{n+1}$, $y_{n+1}$ represent the pixel locations of the 2D watermark before and after transformation respectively. The values of parameters $I$, $a_i$, $b_i$ i and $N_i$ represent the parameter set of GMSAT. As with MSAT, the application of GMSAT requires knowledge of the additional parameter $T_i$ [13]. Complete parameters set of $Key_{\mathrm{I}}$ determines GMSAT and consists of all *I* stages parameters union (3):

$$Key_{\mathrm{I}} = \cup_{i=1}^{I} E_i(a_{i,} b_{i,} k_{i,} N_{i,} T_i) \tag{3}$$

where $E_i$ is $i$-th stage parameter set and operator U(•) represent set union. During scrambling, the original watermark is entered at the entrance of the first stage $E_1$, while the output of the first stage is brought to the entrance of second stage, and so on. At the entrance of the last stage *I*, the exit of the last stage *I*-1 is brought. At the exit of the *I*-th stage, a scrambled watermark is obtained, which is embedded in all frames. Inverse GMSAT is realized using GMSAT $T_i - k_i$ times.

**B. Discrete Wavelet Transformation DWT**

DWT [19] belongs to the class of "*multi-resolution"* – "*multi-leve*l" transformation. These characteristics of the DWT increase the number of possible combinations of the insertion algorithms, since in addition to the level selection, they also offer a choice of insertion sub-bands. In the case of video protection, the watermark can be embedded in the desired DWT transformation sub-band of each frame. By selecting the appropriate transformation sub-band, the embedded watermark can be protected from some kind of interference and attacks. At each level of the DWT, four frequency sub-bands are obtained, which, in this paper are designated as LL, LH, HL and HH.

The LL sub-band is obtained by filtering the frame with a low-pass filter in horizontal and vertical directions. This sub-band carries the greatest energy of the frame. The embedding of a watermark in the LL sub-band may cause significant video degradation, but at the same time ensures the robustness of the watermark in attempt to extract it. The HH sub-band is obtained by filtering a high-pass filter in the horizontal and vertical direction and it contains the high-frequency components of the frame along diagonals. This sub-band includes edges and texture of the frame. Frequency sub-bands HL and LH are obtained by low-frequency filtering in one direction and high frequency filtering in the other direction. The LH sub-band contains information about vertical details corresponding to horizontal edges, while the HL sub-band contains information about horizontal details corresponding to vertical edges. Embedding the watermark in the HL and LH sub-bands is a compromise between the robustness of the watermark and the perceptual quality of the protected video. With the further decomposition of the LL sub-band, the next decomposition level is obtained. The decomposition level depends on the needs of the application, and, in this paper, the second level of DWT decomposition with the known Harr wavelet filter was used. In this way, DWT LL2 resolution and watermark resolution are equalized.

**C. SVD decomposition**

In this paper, SVD decomposition is used as a tool for watermark inserting in video frames. Each frame of the video sequence is presented with three square matrices. In $YC_bC_r$ color space, these are $\boldsymbol{Y}$, $\boldsymbol{C}_b$ and $\boldsymbol{C}_r$ matrices. SVD is based on theorems that any rectangular matrix $\boldsymbol{A}$ of dimension $m \times n$ can be decomposed into three matrices [20]:

$$\boldsymbol{A} = \boldsymbol{U}\boldsymbol{S}\boldsymbol{V}^T \tag{4}$$

where $\boldsymbol{A} \in \Re^{n\times n}$, $\boldsymbol{U} \in \Re^{n\times m}$ and $\boldsymbol{V} \in \Re^{m\times m}$. The $\boldsymbol{U}$ and $\boldsymbol{V}$ matrices are orthogonal matrices, and the columns of these matrices are called left, i.e, right singular vectors. The matrix, $\boldsymbol{S}$ is a diagonal matrix, known as the matrix of singular values. If $r$ is the rank of the matrix $\boldsymbol{A}$, then the elements of the matrix $\boldsymbol{S}$ satisfy the relation (5):

$$\sigma_1 \geq \sigma_2 \geq \cdots \sigma_r \geq \sigma_{r+1} = \sigma_{r+2} = \cdots = \sigma_n = 0, \tag{5}$$

and the matrix $\boldsymbol{A}$ can be represented as follows:

$$\boldsymbol{A} = \textstyle\sum_{p=1}^{r} \sigma_p \boldsymbol{u}_p\, \boldsymbol{v}_p^T\,, \tag{6}$$

where $\boldsymbol{u_p}$ and $\boldsymbol{v_p}$ represent the *p*-th singular vectors of the matrices $\boldsymbol{U}$ and $\boldsymbol{V}$, while $\sigma_p$ is the singular value. Singular vectors specify the matrix $\boldsymbol{A}$ geometry, while the singular values specify the energy (image brightness) of the matrix $\boldsymbol{A}$. If the matrix $\boldsymbol{A}$ presents the Y component of the video frame, then the entire video sequence can be represented by a series of similar matrices. In this paper, SVD transformation is performed over a series of $\boldsymbol{Y}$ matrices representing the illumination of each individual frame. The most important characteristics of the SVD decomposition that are important for this work are the invariance to the transposition, scaling, rotation and replacement of columns and rows. These characteristics are important for preserving the video itself, as well as for ensuring the robustness of the inserted watermark on geometric and other attacks.

## 3. MODIFIED RELIABLE DWT-SVD ALGORITHM

In this paper, the embedding and extracting of the watermark is performed in the SVD domain by a reliable SVD algorithm [21]. A reliable SVD algorithm solves the problem of false positive detection that is characteristic of the standard SVD algorithm [22]. A flow diagram of a modified algorithm for embedding and scrambling the watermark into video frames in the DWT-SVD domain is shown in Fig. 1. Fig. 2 shows a flow diagram of the modified algorithm for extraction of the imbedding scrambled watermark in the DWT-SVD domain. The choice of the DWT decomposition level is influenced by many factors. The compromise between the degradation of the cover image and the quality of the extracted watermark plays a main role. Inserting a watermark at the lower levels of the DWT decomposition causes a greater degradation of the cover image, but also a higher quality of the extracted watermark. On the other hand, increasing the level of DWT decomposition reduces the information capacity and resistance to malicious attacks. In this paper, the second level of DWT decomposition and LL sub-band is selected because it possesses the necessary information capacity and a satisfactory relationship between the degradation of the cover image and the extracted watermark. The details of the algorithm for embedding and extracting the encrypted watermark in the $DWT_2$-SVD domain are represented by a series of the following I and E steps.

### A. Algorithm for watermark embedding

*Step* $I_1$: Decomposition of the Y component of the $\boldsymbol{F}$ frame using the second level DWT (using wavelet type "*Haar*") to obtain $\boldsymbol{F}^k$ i $\boldsymbol{F}^l$ sub-bands:

$$\{\boldsymbol{F}^k, \boldsymbol{F}^l\} = DWT_{2_{Haar}}(\boldsymbol{F}) \quad (7)$$
$$k \epsilon \{LL_2, HL_2, LH_2, HH_2\}$$
$$l \epsilon \{HL_1, LH_1, HH_1\}$$

*Step* $I_2$: SVD decomposition sub-bands $\boldsymbol{F}^k$:

$$\boldsymbol{F}^k = \boldsymbol{U}_F^k \cdot \boldsymbol{S}_F^k \cdot (\boldsymbol{V}_F^k)^T . \quad (8)$$

*Step* $I_3$: Encryption of the original watermark $\boldsymbol{W'}$ (256 gray levels and lower resolution) using GMSAT and obtaining the scrambled watermark $\boldsymbol{W}$ which is inserted in each frame.

$$\boldsymbol{W} = GMSAT_{E_i(a_i, b_i, k_i, N_i)}(\boldsymbol{W'}) \quad (9)$$

$$i = 1,2, \dots I \, .$$

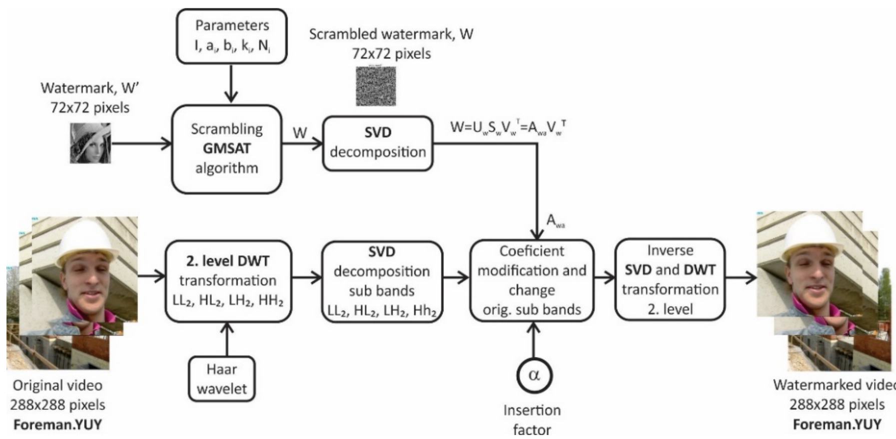



Fig. 1. Flow diagram of the modified algorithm for embedding the scrambled watermark in the DWT-SVD domain.

*Step* $I_4$: SVD decomposition of scrambled watermark $\boldsymbol{W}$ and calculate the *principal component* $\boldsymbol{A}_{wa}$ [21].

$$\boldsymbol{W} = \boldsymbol{U}_w \cdot \boldsymbol{S}_w \cdot \boldsymbol{V}_w^T = \boldsymbol{A}_{wa} \cdot \boldsymbol{V}_w^T \, ; \; \boldsymbol{A}_{wa} = \boldsymbol{U}_w \cdot \boldsymbol{S}_w \, . \tag{10}$$

*Step* $I_5$: Embedding the principal component $\boldsymbol{A}_{wa}$ in the diagonal matrix of the sub-band $\boldsymbol{S}_F^{LL_2}$ by the insertion factor α:

$$\boldsymbol{S}_{F\_1}^{LL_2} = \boldsymbol{S}_F^{LL_2} + \alpha \cdot \boldsymbol{A}_{wa}. \tag{11}$$

*Step* $I_6$: Inverse SVD decomposition and creating a sub-band with the embedded watermark:

$$\boldsymbol{F}^{LL_2} = \boldsymbol{U}_F^{LL_2} \cdot \boldsymbol{S}_{1\_F}^{LL_2} \cdot \left(\boldsymbol{V}_F^{LL_2}\right)^T \, . \tag{12}$$

*Step* $I_7$: Replacement of the original sub-band of the second DWT level with the modified one and application of the inverse DWT to obtain the watermarked frame $\boldsymbol{F}_w$.

$$\boldsymbol{F}_w = IDWT_{2_{Haar}}(\boldsymbol{F}^k, \; \boldsymbol{F}^l) \, . \tag{13}$$

**B. Watermark extraction algorithm**

The process of extracting the watermark $\boldsymbol{W^*}$ from a protected video can be done with the following E steps:

*Step* $E_1$: Decomposition the Y component of the original frame $\boldsymbol{F}$ using the second level of DWT (using wavelet type "*Haar*") to obtain the $\boldsymbol{F}^k$ and $\boldsymbol{F}^l$ sub-bands:

$$\{\boldsymbol{F}^k, \boldsymbol{F}^l\} = DWT_{2_{Haar}}(\boldsymbol{F}) \tag{14}$$

$$k \epsilon \{LL_2, HL_2, LH_2, HH_2\}$$

$$l \epsilon \{HL_1, LH_1, HH_1\}.$$

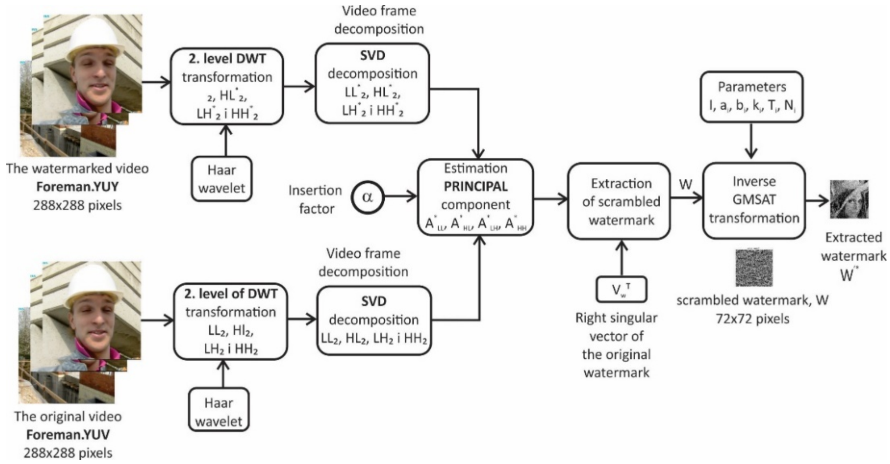



Fig. 2. Flow diagram of the modified algorithm for extracting the scrambled watermark in the DWT-SVD domain.

*Step* $E_2$: SVD decomposition of the sub-bands $\boldsymbol{F}^k$:

$$\boldsymbol{F}^k = \boldsymbol{U}_F^k \cdot \boldsymbol{S}_F^k \cdot (\boldsymbol{V}_F^k)^T \tag{15}$$

*Step* $E_3$: Decomposition of potentially attacked frame $\boldsymbol{F}_w^*$ using a second level of DWT transformation:

$$\{ \boldsymbol{F}_w^{*k}, \boldsymbol{F}_w^{*l}\} = DWT_{2_{haar}}(\boldsymbol{F}_w^*) \tag{16}$$

*Step* $E_4$: SVD decomposition of sub-band $\boldsymbol{F}_w^{*LL_2}$:

$$\boldsymbol{F}_w^{*LL_2} = \boldsymbol{U}_{Fw}^{*LL_2} \cdot \boldsymbol{S}_{Fw}^{*LL_2} \cdot \left(\boldsymbol{V}_{Fw}^{*LL_2}\right)^T \tag{17}$$

*Step* $E_5$: Creating the difference between the original ($\boldsymbol{F}^k$) and the protected ($\boldsymbol{F}_w^{*k}$) frames:

$$\boldsymbol{F}_1^{LL_2} = \boldsymbol{F}_w^{*LL_2} - \boldsymbol{F}^{LL_2} \tag{18}$$

*Step* $E_6$: Calculate the principal component [21]:

$$\boldsymbol{A}_{wa}^{*LL_2} = \frac{\left(\boldsymbol{U}_F^{LL_2}\right)^{-1} \cdot \boldsymbol{F}_1^{LL_2} \cdot \left(\left(\boldsymbol{V}_F^{LL_2}\right)^T\right)^{-1}}{\alpha} \tag{19}$$

*Step* $E_7$: Calculate the inserted encrypted watermark $\boldsymbol{W}'^{*LL_2}$ as follows:

$$\boldsymbol{W}'^{*LL_2} = \boldsymbol{A}_{wa}^{*LL_2} \cdot \boldsymbol{V}_w^T \tag{20}$$

*Step* $E_8$: Decrypting the origin of the encrypted watermark from the $LL_2$ sub-band $\boldsymbol{W}^{LL_2*}$ using the inverse GMSAT:

$$\boldsymbol{W}^{LL_2*} = \underset{E_i(a_i,b_i,k_i,N_i,T_i)}{IGMSAT}(\boldsymbol{W}'^{*LL_2}) \\ i = 1,2,\ldots I\ . \tag{21}$$

## 4. EVALUATION OF THE PROPOSED ALGORITHM

Without compromising the significance of the presented algorithm, in this paper, the .yuv format for storing uncompressed video content is assumed. Note that in this format, information about each video frame is stored in matrices denoted as **Y**, $\mathbf{C}_b$, and $\mathbf{C}_r$. The matrix **Y** stores the illumination values for each pixel of the frame, while the color information is stored in the $\mathbf{C}_b$ and $\mathbf{C}_r$ matrices. Because of the robustness, the embedding of a watermark in an uncompressed domain is performed only in the **Y** matrix. The watermark is inserted into well-known video sequence "*Foreman*" in a modified resolution of 288 × 288 pixels. For evaluation of the proposed algorithm, the first 50 frames of this video sequence were used.

(a) (b) (c) (d) (e)

Fig. 3. The appearance of the watermark (a) the original, after (b) the first (c) second (d) third (e) fourth stage of the G4SAT.

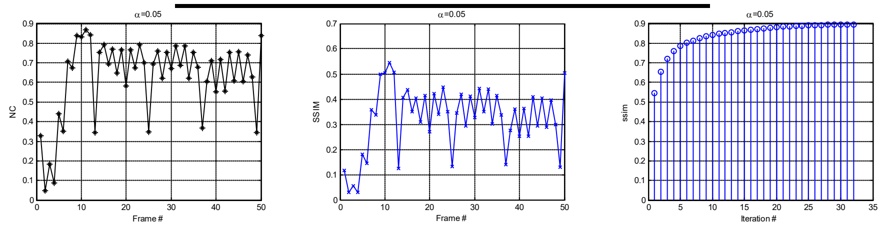
Unlike previous works [11], [12], where the watermark embedding was performed in the DCT-SVD domain, in this paper, the embedding of the watermark was performed in the DWT-SVD domain. The applied embedding and extraction algorithms are shown in sections 3B and 3C respectively.

An adapted central part of well-known image "*Lena.bmp*" in a resolution of 72 × 72 pixels as the watermark in the experimental part of this work was used. The appearance of the original watermark is shown in Fig. 3(a). In order to raise the level of protection, the content of this watermark is scrambled by the GMSAT algorithm. 4-stage GMSAT (G4SAT) with the parameters shown in Table I was applied to scramble the watermark.

Tabele I: Parameters (key) of applied G4SAT

| Parameters | Stages | | | |
|---|---|---|---|---|
| | $\mathbf{E_1}$ | $\mathbf{E_2}$ | $\mathbf{E_3}$ | $\mathbf{E_4}$ |
| a | 2 | 1 | 4 | 3 |
| b | 2 | 1 | 2 | 1 |
| N | 72 | 60 | 50 | 72 |
| k | 9 | 5 | 7 | 7 |

T 12 60 18 18




(a) (b) (c)

Fig. 4. Values (a) NC coefficients (b) SSIM index of extracted watermarks, (c) SSIM index after each iteration of enhancement algorithm - max 0.8956.

Based on the values of parameters $N_1$ and $N_4$ from Tab I, it can be concluded that only in the first and fourth stages Arnold transformation will apply to the entire watermark obtained in the previous stages. In this paper the complete parameter set (22) represents the key $\text{Key}_4$ for scrambling the watermark by G4SAT.

$$Key_4 = E_1 \cup E_2 \cup E_3 \cup E_4. \tag{22}$$

$T_i$ parameters are only used in inverse G4SAT. On Fig. 3(b) - 3(e) the obtained watermarks at the end of each G4SAT stage are displayed. In all G4SAT stages, the spatial decoration of the pixels of the original watermark can be clearly seen. To return the scrambled watermark to the original, it is necessary to have inverse G4SAT, the parameters of all stages as well as the initial conditions of each stage. If only one G4SAT parameter is unknown, it is not possible to decrypt the scrambled watermark. Although the embedding of a watermark can be performed in all DWT sub-bands, in this paper, embedding a scrambled watermark from Fig. 3(e) performed only in the $LL_2$ DWT sub-band of each frame of the video sequence. The encrypted watermark in the DWT-SVD domain with the insertion factor $\alpha = 0.05$ is embedded.

After inserting watermarks into all frames of an uncompressed video, encoding was performed with the H.264/AVC encoder. The protected video sequence is encoded by the JM reference software of the ITU in version 19.0 FRExt [23]. The coding quality is defined by a set of FRExt parameters, and the key parameters are as follows: *IntraPeriod* = 12; *NumberReferenceFrames* = 5; *NumberBFrames* = 1. In the process of proving copyright property, the embedded watermark can be extracted from the decoded protected video. Figure 4(a) shows the values of NC coefficients, and Fig. 4(b) the SSIM index of extracted watermarks in the function of serial number of frames in the video sequence. With these figures, it can be clearly seen that watermarks of variable quality from each frame are extracted. The NC index of extracted watermarks ranged from 0.05 to 0.86, while the SSIM index ranged from 0.05 to 0.52. The higher NC coefficient, that is, the SSIM index represent a better quality of the extracted watermark, and its maximum value is 1. In order to improve the quality of the extracted watermark, an advanced quality correction algorithm was applied [11]. The number of iterations of this algorithm is significantly higher than the number of iterations when using the DCT-SVD domain for inserting a watermark. In this case, the correction algorithm of the extracted watermark made 32 iterations of Figure 4 (c), while in [11] it carried out only 12 iterations. Larger number of iterations of this algorithm has also


Fig. 5. Appearance (a) of the original watermark, (b) of the watermark extracted from the 50th frame and (c) the watermark after the application of the advanced corrected algorithm.

provided a higher quality of the extracted watermark. Fig. 5(a) shows the appearance of the original watermark, in Fig. 5(b) the appearance of the watermark extracted from the 50th frame, while in Fig. 5(c) shows the appearance of a corrected watermark from the first 50 frames of protected video. The normalized cross-correlation coefficient for the corrected watermark is NC = 0.9852, while its SSIM index is 0.8956. The obtained results justify the application of the proposed algorithm because, in comparison with the results published in [17] (NC = 0.9824), a slightly higher NC coefficient was realized.

## 5. CONCLUSION

This paper presents the protection of video content by embedding a scrambled watermark in the DWT-SVD domain. Insertion was performed at the second level of DWT, and a reliable SVD-based algorithm was used. Prior to inserting, the watermark is encrypted with GMSAT with four stages, thus bringing safety to a higher level. To decrypt the extracted watermark, inverse GMSAT was used, for which the knowledge of the periods of all stages is required. The quality of extracted watermarks was evaluated by objective parameters such as SSIM and NC. In comparison with the results obtained for insertion into the DCT-SVD domain, a larger SSIM index of the extracted watermark was realized by about 32.3%. This significant increase in the SSIM index can be attributed to the higher average SSIM index of extracted watermarks, as well as to a greater number of iterations of the repair algorithm. In our further research, the possibilities of inserting watermarks into other DWT sub-bands and their impact both on the quality of the protected video and on the quality of the extracted watermark will be examined.

## REFERENCES

[1] I. Cox, M. Miller, J. Bloom, J. Fridrich, T. Kalker, *Digital Watermarking and Steganography*, Elsevier, 2008.
[2] M. Jevtović and Z. Veličković, "*Protokoli prepletenih slojeva*", Akademska misao, Beograd, 2012.
[3] M. Mitrea, F. Preteux, A. Vlad, "Spread spectrum Colour Video Watermarking in the DCT domain," Journal of Optoelectronics and Advanced Materials, Volume 7, No. 2, pp. 1065-1071, Apr. 2005.

[4] C. W. H. Fung and W. Godoy, "A novel DWT-SVD video watermarking scheme using side view," 5th International Conference on Signal Processing and Communication Systems (ICSPCS), Honolulu, HI, 2011, pp. 1-4.

[5] S. Stankovic, I. Orovic, N. Zaric, C. Ioana, "Two Dimensional Time-Frequency Analysis based Eigenvalue Decomposition Applied to Image Watermarking," Multimedia Tools and Applications, Volume 49, No. 3, pp.529-543, 2010.

[6] S. Stankovic, I. Orovic, M. Chabert, B. Mobasseri, "Image Watermarking based on the Space/Spatial-Frequency Analysis and Hermite Functions Expansion," Journal of Electronic Imaging, Volume 22, No. 1, 013014, 2013.

[7] A. Rakesh, S. S. Bedi, "All Aspects of Digital Video Watermarking Under an Umbrella", International Journal of Image, Graphics & Signal Processing, Vol. 7 Issue 12, pp 54-73, 2015.

[8] Z. Shahid, M. Chaumont, W. Puech, "Considering the reconstruction loop for data hiding of intra- and inter-frames of H.264/AVC", Sig., Image and Video Process. , Vol. 7, No. 1, pp. 75-93, 2013.

[9] B. Gunjal, S. Mali, "MEO based secured, robust, high capacity and perceptual quality image watermarking in DWT-SVD domain", SpringerPlus, 2015, doi:10.1186/s40064-015-0904-z.

[10] T. Thanh, K. Tanaka, "The novel and robust watermarking method based on q-logarithm frequency domain", Multimedia Tools and Applications, Vol. 75 Iss. 18, pp. 11097-11125, 2016, https://doi.org/10.1007/s11042-015-2836-6.

[11] Z. Veličković, Z. Milivojević, M. Veličković, M. Jevtović, "The impact of prediction structures H.264 encoder on the quality of the extracted watermark from the chaos domain", *ETF Jour. of Electrical Engineering*, vol. 22 , pp. 111-121, Podgorica, 2016.

[12] Z. Veličković, M. Veličković, Z. Milivojević, "Improved Gray-Scale Watermark Encryption Based on Chaotic Maps", in *Proc. UNITECH*, 2016, pp. II-145-150, Gabrovo.

[13] Z. Veličković, M. Veličković, "Bezbednost videa žaštićenog vodenim žigom skremblovanim GMSAT algoritmom", in *Proc.* INFOTEH, pp. 236-242, Jahorina 2017.

[14] N. Nikolaidis, A. Tefas, I. Pitas, „Chaotic sequence for digital watermarking", Adv. in Nonlinear Signal and Image Processing, Ed. S. Marshall and G. L. Sicuranza, Hindawi, 2006, pp. 205-23.

[15] Z. Veličković, Z. Milivojević, M. Veličković "The Insertion of the Encrypted Low-Resolution Watermark in the Uncompressed Video", in *Proc.* ICEST 2016, pp. 191-194, Ohrid, 2016.

[16] R M. Ibrahim, N. Kader, M. Zorkany, "Video Multiple Watermarking Technique Based on Image Interlacing Using DWT," The Scientific World Journal, Hindawi, Vol. 2014.

[17] D. Singh, S.K. Singh, "DWT-SVD and DCT based robust and blind watermarking scheme for copyright protection", *Multimedia Tools and App.*, vol. 76, no. 11, pp. 13001–13024, june 2017.

[18] *Advanced Video Coding for Generic Audiovisual Services*, Recommend. ITU-T H.264, Feb. 2016.

[19] M. Vetterli, J. Kovačević, *Wavelets and Subband Coding*, Prentice Hall, Englewood Cliffs, NJ, 1995.

[20] R. Liu, T. Tan, "An SVD-Based Watermarking Scheme for Protecting Rightful Ownership", *IEEE Transactions on Multimedia*, vol. 4, no. 1, pp. 121-128, March 2002.

[21] C. Jain, S. Arora, P. Panigrahi, "A Reliable SVD based Watermarking Scheme", *Journal CoRR*, vol. abs/0808.0309, 2008. [Online]. Available http://dbpl.uni-trier.de/

[22] J.M. Guo, H. Prasetyo, „False-positive-free SVD-based image watermarking," J. Vis. Commun. Image Represent. 25 (2014), pp. 1149–1163.

[23] "JM reference software version 19.0," iphome.hhi.de, [Online]. Available: http://iphome.hhi.de/suehring/tml/.