THE IMPACT OF THE PREDICTION STRUCTURE IN THE H.264 ENCODER ON THE QUALITY OF THE EXTRACTED WATERMARK FROM THE CHAOS DOMAIN

Zoran Veličković [*], *Zoran Milivojević* [**], *Marko Veličković* [***], *Milojko Jevtović* [****]

Keywords: *Chaotic maps, Copyright protection, H.264/AVC codec, Watermark.*

Abstract: Secure sharing of the digital video content over the Internet requires the use of modern techniques of protection. This paper describes the insertion of the encrypted watermark in the uncoded video content as a way of protecting copyrights. The impact of the prediction structure in the H.264 encoder to the survival of the inserted watermark is tested for two schemes. The watermark is encrypted with multistage Arnold transformation, and on the reception, an advanced algorithm for the realized by the SSIM index 0.71521 for an IBBBBBP scheme has been applied. The results obtained through the displayed example justify the application of multistage Arnold transformation for the video copy protection and raise security to a higher level.

1. INTRODUCTION

The exchange of the digital multimedia content on the Internet has become the dominant form of network traffic [1]. Around 64% of global IP traffic is related to some form of video communications [2]. The easy availability of the multimedia content, especially a

[*] Z. Veličković is with the College of Applied Technical Sciences Niš, Serbia, (phone +381 69 468 7155, e-mail: zoran.velickovic@vtsnis.edu.rs)

[**] Z. Milivojević is with the College of Applied Technical Sciences Niš, Serbia, (phone +381 63 860 9206, e-mail: zoran.milivojevic@vtsnis.edu.rs)

[***] M. Veličković is with College of Applied Technical Sciences Niš, Serbia, (phone +381 69 393 4416, e-mail: marko.velickovic93@yahoo.com).

[****] M. Jevtović is with the Engineering Academy of Serbia, Belgrade, Serbia, (phone +381 64 131 9139, e-mail: vladmijev@ptt.rs).

video, was crucially influenced by this fact. Web portal YouTube played a special role, giving opportunity to each Internet user to upload his/her own video content on the website, and thus make it globally accessible. Another reason in favor of this fact was related to technical aspects of the digital multimedia content. Unlike analog, in multiple copying of the digital multimedia content there was no drop in quality of copies. In fact, all copies of the digital multimedia content were equal to each other and identical to the original.

These characteristics of the digital multimedia content are favorable for the phenomenon of piracy, that is, illegal copying and distribution of the multimedia content on the Internet. Piracy of the multimedia content is specifically expressed in film, music and TV industry. From the total of the pirated multimedia content 35.2% belongs to the illegal film market, 14.5% to the pirated TV content and 2.6% to the music content [3]. Financial losses as a result of the piracy of multimedia contents in the modern world are measured in billions of dollars [4].

For copy protection of the digital multimedia content standard cryptographic techniques can be applied, but for practical application, the methods based on inserting a watermark into a multimedia content are much more efficient. A good feature of multimedia applications that are to some extent tolerant on packet loss [5], is actually an aggravating circumstance for the implementation of standard cryptographic techniques. Therefore, cryptographic technology based on PKI (Public Key Infrastructure) is rarely used for this purpose.

The watermark can be inserted into the encoded [6] and uncoded video domain [7]. The insertion of the original watermark in the image is considered in [8], while the original watermark insertion in the uncoded video is discussed in [9]. To protect the contents of the watermark, prior to its insertion into a multimedia content, the encryption, i.e. scrambling should be done. In this paper, the techniques of the invertible Chaotic Maps [10] for scrambling the contents of the watermark are used. This paper discusses the scrambled watermark insertion in the uncoded video domain. In [11] - [16] a technique for watermark scrambling using Arnold transformation which is then inserted into the image, i.e. video frames, is used.

In [11] - [13] a standard form of Arnold transformation is used, while in [13] - [16] hybrid techniques for watermark scrambling are used. Hybrid techniques in the first step use a parameterized form of Arnold transformation that belongs to a group of two-dimensional (2D) chaotic maps. In [13] a standard form is used, in [14] one-parameter is used, and in [15] and [16] two-parameter Arnold transformation is used. In the second step of hybrid techniques in [13] a cross-chaotic map is applied, in [14] a modification of the histogram is applied, in [15] and [16] additional parametric Arnold transformation is applied. This paper proposes the use of the generalized multistage parametric 2D Arnold transformation [16] in contrast to [13] - [15] that use double watermark encryption. The benefits brought by the application of multistage Arnold transformation is primarily related to the arbitrary increase cryptographic space. With increasing a cryptographic space the protection level in the multimedia content from unauthorized copying is enhanced.

To obtain the original watermark content from scrambling, it is necessary to apply the inverse multistage Arnold transformation [16]. In addition to knowing the transformation parameters for the application of the inverse Arnold transformation, it is extremely important to know the initial conditions of transformation. Small variations in the initial conditions completely change the behavior of a system based on chaotic maps. In this paper the enhanced reliable SVD algorithm [9] in the DCT domain for the insertion of the encrypted watermarks is applied, while in [13] the technique for inserting "pixel by pixel" is used. In [8] and [12] - [15], the watermark is inserted into the picture, while in this paper as well as in [7], [9], [11] and [16] the watermark is inserted into a video, namely, in each frame of the uncoded video. In contrast to [7] and [11], the protected video is encoded by the H.264/AVC encoder in order to be presented to users. As the process of the encoding video belongs to the class of compression with losses, it has a negative effect both on the video quality, as well as on the inserted watermark quality. It is known that the encoded video quality may affect a set of coding parameters with the H.264/AVC encoder grouped into profiles. Profiles, among other things, can influence the selection of a prediction structure that will be applied in coding. In the practical part of the paper the Main profile of the H.264/AVC encoder is used, which implies the existence of the I, P and B frames with the appropriate predictive structures that are identified in this paper as IBPBPBP and IBBBBBP. Depending on the coding profiles and applied prediction structure, it leads to neglecting details of video frames, as well as to the contents of the injected watermark. This fact imposes the use of algorithms to repair the quality of the extracted watermark from the video. In this paper the advanced algorithm for correcting the quality of the extracted watermark from the decoded video [9] is used.

The rest of the paper is structured as follows. The second section presents multistage Arnold chaotic 2D maps for scrambling the content of the watermark. The third section briefly shows the characteristics of the H.264/AVC encoder and the available code profiles are described. The fourth section presents the application of 3-stage Arnold transformation for scrambling the watermark. The extracted watermarks of the improved quality from the video coded by a variety of predictive structures are also presented. In the fifth section corresponding conclusions based on conducted tests are derived.

2. INVERTIBLE HAOTIC MAPS

To improve the security system of the copyright protection digital video contents, the scrambling watermark techniques are often used. In this paper the cryptographic techniques based on the chaotic 2D maps that belong to the class of deterministic systems whose behavior is highly dependent on initial conditions [10] are applied. Starting from the very close initial conditions, the chaotic 2D maps will generate quite different orbits. This feature of the chaotic maps is extremely exploited in systems of cryptographic protection. In this paper the purpose of implementing a 2D chaotic map is to make the relocation pixel of the original image in order to perform spatial decorrelation of adjacent pixels. The 2D chaotic maps have to possess inversion iterative algorithms to restore the original content in order to successfully implement the video content protection system. Generally, the chaotic 2D maps can be described by the equation (1):

$$\mathbf{x}_{n+1} = (\mathbf{A}\mathbf{x}_n) \bmod N, \quad \mathbf{x} \in (0,1,\ldots,N-1) \times (0,1,\ldots,N-1). \tag{1}$$

The vector **x** represents the pixel location, **A** is the transform matrix, N is the dimension of the square image, and $n \in Z$ is the number of the iteration.

A. Arnold transformation

In this paper the chaotic 2D invertible maps known as Arnold transformation [9] - [16] for digital watermark scrambling are used. The parameterized form of Arnold transformation is given by equations (2) and (3).

$$\begin{bmatrix} x_{n+1} \\ y_{n+1} \end{bmatrix} = \left(\begin{bmatrix} 1 & b \\ a & ab+1 \end{bmatrix} \begin{bmatrix} x_n \\ y_n \end{bmatrix} \right) \bmod N \tag{2}$$

$$(x, y) \in (0,1,2, \ldots, N-1) \times (0,1,2, \ldots, N-1). \tag{3}$$

The arranged pairs (x_n, y_n) and (x_{n+1}, y_{n+1}) are the coordinates of the image pixel (in our case the watermark) before and after transformation, respectively. The symbols a and b are positive integers that represent known parameters of Arnold transformation, and parameter $N \in Z$ represents the dimension of the square watermark in pixels.

It should be noted that, according to the definition, the determinant of the transformation matrix A equals 1, and thus, a transformational space is preserved. The main benefit of Arnold transformation is practically the watermark encryption, so that its content is not recognizable to the eye of the beholder. Another important feature of Arnold transformation is that it has a cyclical nature, i.e. after T iterations of Arnold transformation the initial image is received (in our case the original watermark).

The period T depends on the transformation parameters N, a, and b, but there is not a generalized analytical method for its calculation. The determination of the period T is usually done in practice with successive applications of Arnold transformation and analysis of the obtained results. If Arnold transformation is applied k times, the original image is obtained by the inverse Arnold transformation (further application of Arnold transformation T-k times).

B. Multistage Arnold transformation

The basic idea of multistage Arnold transformation is based on the sequential application of multiple Arnold transformation (stages) with different parameters. The transformation parameters of i-th stage a_i, b_i, a number of the consecutive iterations k_i and a period of Arnold transformation stage T_i actually represent the keys for watermark encryption/description. It is clear that with the increasing number of stages in multistage Arnold transformation the number of transformation parameters is growing which exponentially increases the transformation and search space. Fig. 1 shows the example of 3-stage Arnold transformation (solid line) and inverse 3-stage Arnold transformation (dashed line), which was later applied in the practical part of the work.

The original watermark W is brought to the entrance of 3-stage Arnold transformation, while at the exit of the third stage the transformed watermark W^T which is later inserted into each frame of the uncoded video is obtained. The extracted encrypted watermark from the video is marked with W^{T*}, while the extracted decrypted watermark is indicated by $W^{\wedge}$.

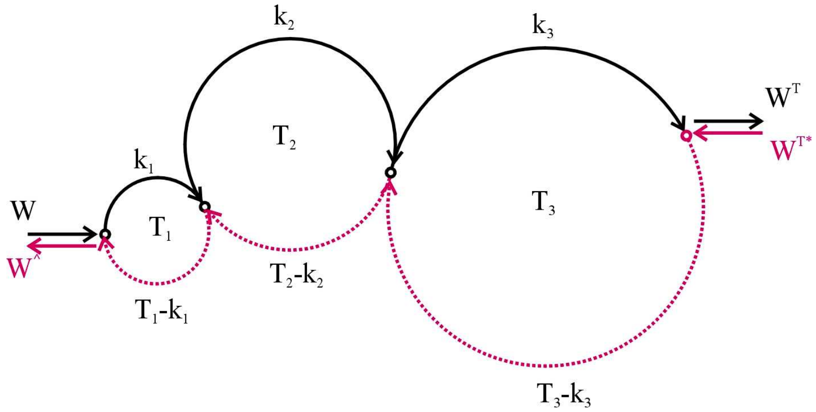


Fig. 1. An example of 3-stage Arnold transformation (solid line) and inverse Arnold transformation (dashed line) with the following parameters: $k_1 = 8$ $T_1 = 24$, $k_2 = 31$, $T_2 = 48$ and $k_3 = 12$, $T_3 = 96$.

A pseudocode for the implementation of multistage Arnold transformation and inverse multistage Arnold transformation are shown on Fig. 2 [16]. In this paper a modified algorithm based on SVD decomposition for inserting the watermark in the uncoded video which eliminates the false positive problem is used. The details of a modified algorithm of the watermark embedding, extraction and repairing are described in [9].

```
% Multistage Arnold transformation
Input   W- Original Watermark
              (matrix N×N)
          I – The number of stages in
              multistage Arnold transform.
          a_i, b_i – Parameters of i-th
              stage 1 ≤ i ≤ I;
          k_i – The number of iterations of
              i-th stage, 1 ≤ i ≤ I;
for i = 1 to I
   for n = 1 to k_i
      W ← Arnold_transform(W, a_i, b_i)
   end
end
Output  W^T=W – Transformed Watermark
```

a)

```
% Inverse multistage Arnold transformation
Input   W^T-Transformed Watermark
              (matrix N×N)
          I – The number of stages in
              multistage Arnold transform.
          a_i, b_i – Parameters of i-th
              stage 1 ≤ i ≤ I;
          k_i – The number of iterations of
              i-th stage, 1 ≤ i ≤ I;
          T_i – The perod of i-th stage
for i = 1 to I
   for n = 1 to T_i - k_i
      W^T ← Arnold_transform(W^T, a_i, b_i)
   end
end
Output  W=W^T - Original Watermark
```

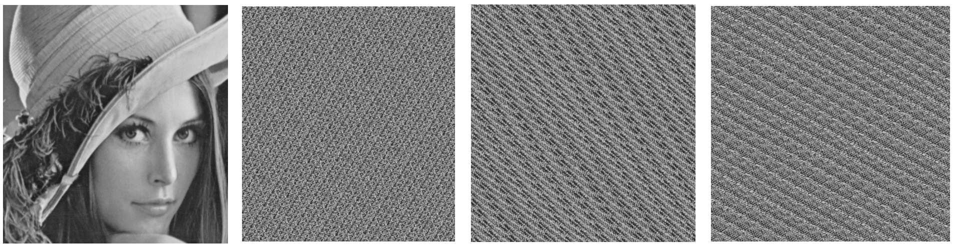
b)

Fig. 2. Pseudocode for a) Multistage Arnold transformation b) Inverse multistage Arnold transformation.

3. H.264/AVC CODEC

The compression algorithms of the H.264/AVC codec belong to the class of algorithms with losses. These algorithms achieve high degree compression based on the prediction of the previous content, current and future frames, called reference frames. Reliability prediction is achieved by motion compensation between the reference and current frame. So, we differ frames type I (intra), P (inter), B (bidirectional), SP and SI which use one or more (past or future) reference frames. Anticipating the contents of certain parts of the image based on the perceived similarities, it is possible to form a "residual frame" with significantly less data. The consequence of this approach is neglection of fine details in the frame which has a negative effect both on the video frame and inserted watermark. The consequence of this approach is variable video quality.

In the previous papers the iterative algorithm of the inserted watermark repair in the H.264/AVC encoder [9] is described. To facilitate the implementation of the H.264 standard in the widest possible set of devices (of different quality and formats), determined profiles with a set of tools for generating the compressed video stream are formed. The H.264/AVC standard defines the following profiles: Baseline, Extended, Main, and High. The Main profile includes the I, P and B frames, as well as tools for enhancing resistance to streaming errors. For professional use, the standard version of the H.264/AVC encoder is extended by adding new coding tools. This extended version is known as FRExt. A FRExt version of the H.264/AVC standard is enriched with new High Profile (HP).



a) b) c) d)

Fig. 3. The appearance of the watermark a) original b) after the first stage b) after the second stage, and c) after the third stage of 3-stage of Arnold transformation.

This paper use the Main profile with GoP (Group of Pictures) of 12 frames to encode a video. To test the quality of the protected video and the quality of the extracted watermark, two prediction structures with one, or with five B frames marked with IBPBPBP and IBBBBBP are tested.

4. EXPERIMENTS AND RESULTS

In the paper a central part of the famous image „Lena“ in resolution 288 × 288 pixels is used as the watermark. Fig. 3 shows the layout of the watermark through all three stages of the applied multistage Arnold transformation. The parameters of the applied three-stage Arnold transformation are $a_1 = 1$, $b_1 = 1$; $a_2 = 4$, $b_2 = 2$; $a_3 = 5$, $b_3 = 8$ respectively. The watermark obtained after the third stage (Fig. 3d) is inserted into each frame of the video. In the shown experiments first 50 frames of the uncoded video stream "Foreman.cif" in amended resolution 288 × 288 pixels are used. The constant factor injection α = 0.05 for inserting the watermark in all frames [9] is used. Encoding/decoding of a video sequence with JM reference software of ITU (International Telecommunication Union) in 18.4 FRExt version is performed. Quality encoding is defined by large set of FRExt parameters. The following FRExt parameters have a key influence on the selection of a prediction structure:

IntraPeriod=12,
NumberReferenceFrames=5 (for both prediction schemes),
NumberBFrames=5 (IBBBBBP scheme),
NumberBFrames=1 (IBPBPBP scheme).

It has been already known that in the process of the encoded video the neglection of some image details occurs in order to increase the compression of the encoder. This paper shows that, depending on the applied code profile, it may affect on the viability of the inserted watermark into the encoded video. The inserted watermark in each frame adversely affects the quality of the video.

The extremely high levels of PSNR (Peak Signal-to-Noise Ratio) 36.5-37dB for each frame of the decoded sequence (Fig. 4) confirm the high quality of the protected video. Fig. 4 (left) shows the PSNR value for the first 50 frames of the decoded video for an IBBBBBP prediction structure, while the right side shows the PSNR value for an IBPBPBP prediction structure. Generally, in Fig. 4 a consistent quality of the decoded frames for both structures can be seen.

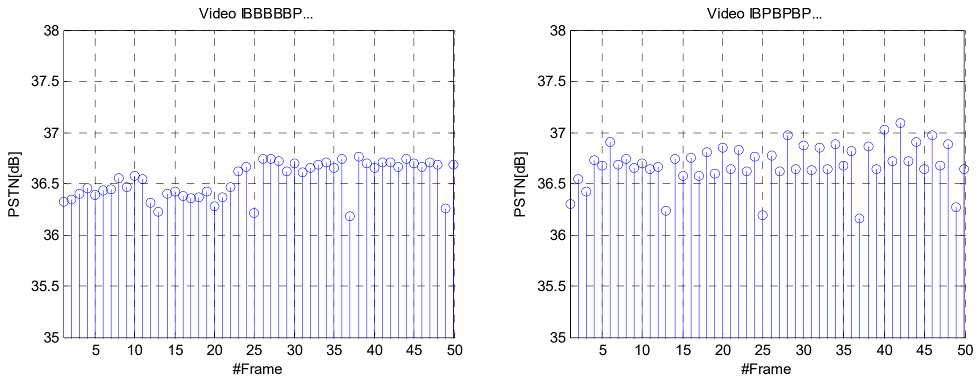


Fig. 4. PSNR for each frame of the decoded video sequence of an IBBBBBB structure (left) and an IBPBPBP structure (right).

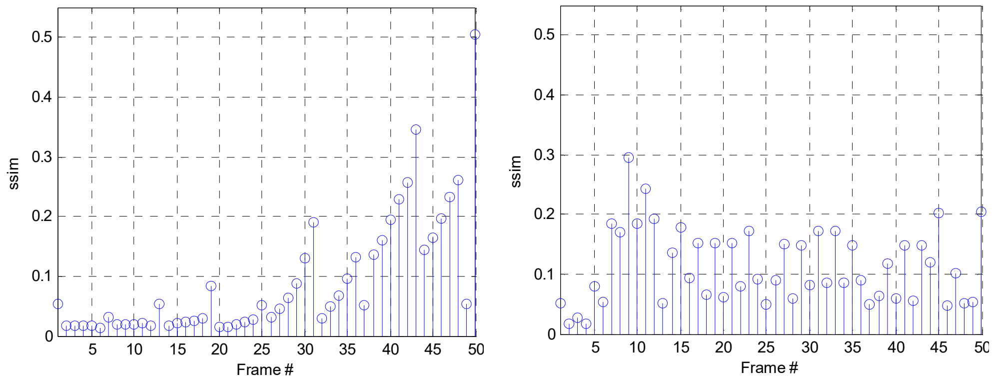


Fig. 5. SSIM indices of extracted watermarks from video encoded by an IBBBBB structure (left) and IBPBPBP predictive structure (right).

The quality of the extracted watermarks is evaluated by the SSIM (Structural Similarity) index [17] whose values are in the range [0 1]. The value of the SSIM index equals 1 when the extracted watermark is identical to the original. SSIM indices for all extracted watermarks are shown in Fig. 5 for both prediction structures.

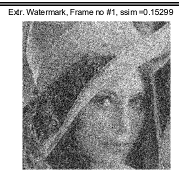
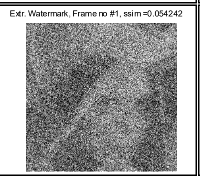
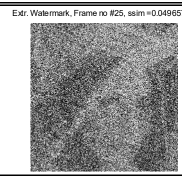
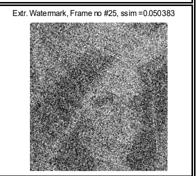
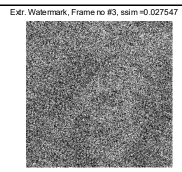
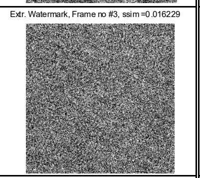
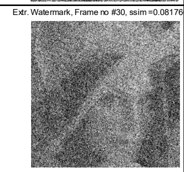
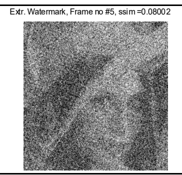
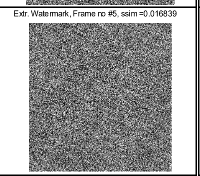
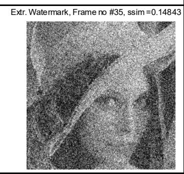
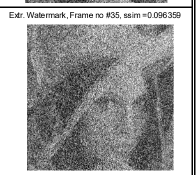
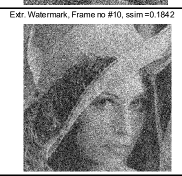
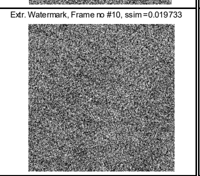
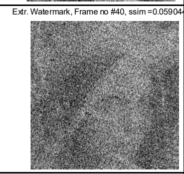
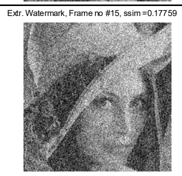
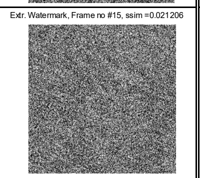
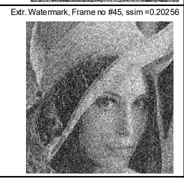
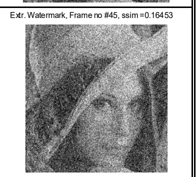
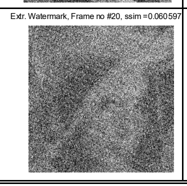
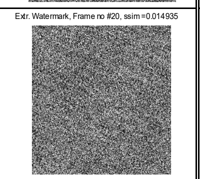
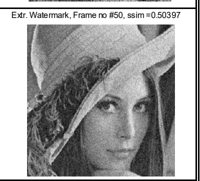
However, in Fig. 5 we can see completely different behavior of SSIM indices for considered prediction schemes. Fig. 5 (left) clearly shows a progressive increase of SSIM indices with the increasing number of frames for an IBBBBBP prediction structure, while this conclusion is not valid for an IBPBPBP prediction structure (right).

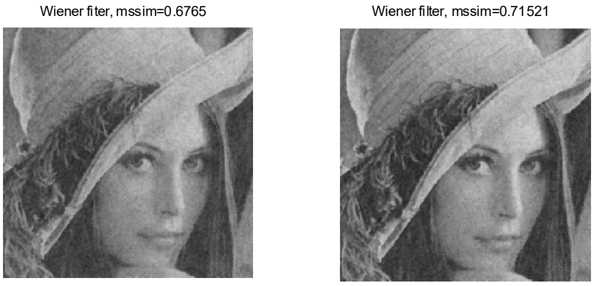
The variable quality of the extracted watermarks from frames 1, 3, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 for both the prediction schemes can be seen in Table 1. This is the indicator for the use of the advanced algorithm for correcting the quality of the extracted watermarks from the video [9]. Comparing the second and third, and fifth and sixth column of Table 1 we can see slightly higher mean value of the SSIM index of the extracted watermarks for an IBPBPBP prediction structure. It should be noted that the value of the SSIM index of the watermark extracted from a 50th frame of an IBBBBBP scheme is 0.50397. This value of the SSIM index has a crucial influence on improving the quality of the extracted watermark [9].

Fig. 6 shows the corrected extracted watermarks from the video encoded by a) an IBPBPBP scheme and b) an IBBBBBP scheme. The SSIM index of the extracted watermark obtained by the advanced algorithm for quality correction is 0.6765 for an IBPBPBP scheme, i.e. 0.71521 for an IBBBBBP coding scheme. It is evident that an IBBBBBP code prediction scheme provides higher quality thanks to the advanced watermark algorithm for correcting the quality of the extracted watermark.

The maximum SSIM index value of the extracted watermark is of great importance for the applied advanced algorithm. This is the basic reason why the IBBBBBP scheme has realized higher SSIM index in only 10 iterations of the advanced iterative algorithm. On the other hand, the advanced algorithm for correcting the quality has realized lower SSIM index of 0.6765 in 20 iterations for an IBPBPBP scheme.

Table I
The appearance of the extracted watermarks from frames with sequence numbers 1, 3, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 video sequences "*Foreman.cif*" encoded by IBPBPBP and IBBBBBP prediction structures.

<table>
<tr><th rowspan="2">Frame Num.</th><th colspan="2">Extracted Watermark</th><th rowspan="2">Frame Num.</th><th colspan="2">Extracted Watermark</th></tr>
<tr><th>IBPBPBP</th><th>IBBBBBP</th><th>IBPBPBP</th><th>IBBBBBP</th></tr>
<tr><td>1</td><td></td><td></td><td>25</td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td>30</td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td><td>35</td><td></td><td></td></tr>
<tr><td>10</td><td></td><td></td><td>40</td><td></td><td></td></tr>
<tr><td>15</td><td></td><td></td><td>45</td><td></td><td></td></tr>
<tr><td>20</td><td></td><td></td><td>50</td><td></td><td></td></tr>
</table>



a) b)

Fig. 6. The appearance of the repaired watermarks from video sequences encoded by prediction schemes a) IBPBPBP and b) IBBBBBP.

5. CONCLUSIONS

There is an obvious need to protect a video content in the age of modern Internet. This paper presented the use of the watermark techniques inserted in the uncoded video for its own protection. The original watermark was encrypted using three-stage Arnold transformation of video encoding/ decoding done by the H.264/AVC codec.

The impact of the encoding scheme on the quality of the extracted watermark was tested on two prediction structures. To decrypt the extracted watermark, the inverse multistage Arnold transformation with three stages was used. For the repair quality of the extracted watermark, the advanced algorithm which was realized as a better SSIM index in 10 iterations for the IBBBBBP scheme was applied. The lack of the implementation of Arnold multistage transformation was necessary for frame processing in additional processing time. The obtained results justified the use of multistage Arnold transformation of video copyright protection and raised security to a higher level.

REFERENCES

[1] M. Meeker, “Internet trends 2015 – code conference”, 2015, http://kpcb.com/InternetTrends [Accessed: Sep. 6, 2016]

[2] Cisco White Paper, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015–2020”, Feb. 2016.

[3] http://www.go-gulf.com/blog/online-piracy/ [Accessed: Sep. 6, 2016]

[4] http://moviepilot.com/posts/2889420 [Accessed: Sep. 6, 2016]

[5] M. Jevtović and Z. Veličković, *Protokoli prepletenih slojeva*, Akademska misao, Beograd, 2012.

[6] R. Ahuja, S. S. Bedi, “All Aspects of Digital Video Watermarking Under an Umbrella”, *I.J. Image, Graphics and Signal Processing,* Vol. 12, pp. 54-73, 2015.

[7] D. Pröfrock, M. Schlauweg, E. Müuller, “A New Uncompressed-Domain Video Watermarking Approach Robust to H.264/AVC Compression”, *Proc. of Signal Processing, Pattern Recognition and Applications* – SPPRA, 2006.

[8] R. S. Run, S. J. Horng, J. L. Lai, T. W. Kao, R. J Chen, "An improved SVD-based watermarking technique for copyright protection", *Expert Systems with Applications*, Vol. 39(1), pp. 673-689, 2012.

[9] Z. Veličković, Z. Milivojević, M. Jevtović, "The Improved Iterative Algorithm for the Enhancement of the Extracted Watermark from Video Streaming in a Wireless Environment", *ETF Jour. of Electrical Engineering*, Vol. 21, pp. 93-107, 2015.

[10] N. Nikolaidis, A. Tefas, I. Pitas. "Chaotic Sequences for Digital Watermarking", in *Advances in Nonlinear Signal and Image Processing*, S. Marshall and G. L. Sicuranza, Eds. Hindawi, 2006, pp. 205-235.

[11] M. Ibrahim, N. Kader, M. Zorkany, "Video Multiple Watermarking Technique Based on Image Interlacing Using DWT," *The Scientific World Journal*, Vol. 2014, http://dx.doi.org/10.1155/2014/634828.

[12] B. Nandeesh, L. Meti, G. K. Manjunath, "A Robust Non-Blind Watermarking Technique for Color Video Based on Combined DWT-DFT Transforms and SVD Technique", *I.J. Inf. Tech. and Computer Science,* Vol. 6, No 9, pp. 59-65, 2014.

[13] C. Pradhan, V. Saxena, A. K. Bisoi, "Imperceptible Watermarking Technique using Arnold's Transform and Cross Chaos Map in DCT Domain", *Int. Jour.of Comp. Applications*, Vol. 55, No. 15, pp. 50 – 53, 2012.

[14] E. Chrysochos, V. Fotopoulos, M. Xenos, A. N. Skodras, "Hybrid watermarking based on chaos and histogram modification", *Sig. Im. Video Proc*, pp. 843-857, 2014.

[15] L. Sun, J. Xu, X. Zhang, Y. Tian, "An Image Watermarking Scheme Using Arnold Transform and Fuzzy Smooth Support Vector Machine", *Math. Prob. in Engineering*, Vol. 2015, http://dx.doi.org/10.1155/2015/931672.

[16] Z. Veličković, Z. Milivojević, M. Jevtović, „Multi-stage Arnold transformation for 2D watermarking encryption", Vol. 2, pp. 130-135, *UNITECH*, 2015.

[17] Z. Wang, A. Bovik, H. Sheikh, E. Simoncelli,"Image Quality Assessment: From Error Visibility to Structural Similarity", *IEEE Trans. on Image. Proc*., Vol. 13, No. 4, 2004.