BLIND WATERMARKING SCHEME IN CHROMINANCE CHANNEL BASED ON SVD AND BIT-PLANE DECOMPOSITIONS

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Abstract

This paper presents the protection of a digital video from copying by inserting a watermark into its contents. Inserting the watermark was performed in the uncompressed domain of the chrominance of the video frame in order to make the interference caused by insertion less visible. The proposed algorithm is based on the specifics of the SVD applied to the block size of 4x4 pixels and belongs to the class of blind algorithms. In the video frames, the components of the black-and-white watermark, which are obtained by bit-plane decomposition, are cyclically inserted. On the receiving side, the extracted watermark components are combined in order to form the black and white watermark. The presented algorithm enables high quality watermark extraction with slightly degradation of video content. The extraction process does not require knowledge of the original content of the video and watermark. The proposed algorithm can be efficiently used to protect video from copying and illegal distribution.

Keywords: Bit-plane, Watermarking, Video, SVD, YUV color format.

INTRODUCTION

High network bandwidth, reduced packet latency as well as modern communication protocols of new generation networks have enabled the exchange of quality multimedia content. Exposing private multimedia content on the network, such as audio messages, photos and video content, has resulted in abuse and increased security risks [1]. Classical information security systems based on message encryption are not applicable to multimedia content. The enormous amount of data to be transmitted when exchanging multimedia content disables the efficient operation of classical cryptographic algorithms in real time. An even greater drawback of standard cryptographic techniques is that they protect multimedia content only during transfer through communication channels. The problem with this information security concept is that on receiving, for reproduction, multimedia content must be decrypted, which potentially make them unsafe. In order to prevent the illegal use and leak of private media information, numerous techniques have been developed to protect these content. Inserting invisible secret information (watermark) in multimedia content is often used technique in order to increase information security on the Internet. In addition to using multimedia copy protection [2], watermark techniques can also be used for personal biometric identification [1] as well as for checking the integrity of multimedia content. The watermark can have a form of color image, black-and-white (grayscale) images, or binary images. In this paper, several different binary images are inserted into the multimedia content obtained by the decomposition of the black and white watermark [3].

The main problem with this protection concept is that inserting a watermark leads to interference in multimedia content. A stronger inserted watermark results in a reduction the quality of multimedia content, but it ensures the extraction of a higher quality watermark. On the other hand, the weakly inserted watermark less degrades the quality of the multimedia content, but does not provide high-quality watermark extraction [1], [3]. In order for the watermark to be used in the process of proving ownership, extraction of a high quality watermark from a protected multimedia content is necessary. Clearly, these are two opposing requirements that the multimedia content algorithm must reconcile. In the continuation of this paper, basic color models of video, SVD and bit-plane decomposition of the bit of mapped images are shown. The insertion model, or the extraction of a decomposed watermark into multiple frames in the color domain of video, is an algorithm recommended in this paper. Evaluation of the proposed method was carried out and the obtained results were analyzed. In the last section, certain conclusions and recommendations were made.

BACKGROUND

Watermarking techniques can be implemented in different information domains. Thus, secret information - a watermark can be inserted into a spatial domain, one of a number of transformation domains, or a chaos domain. In order to improve the characteristics of individual watermarking algorithms, hybrid models are often used to combine the good properties of two or more information domains. If watermark extraction methods require original video content or the original watermark is called nonblind methods [4]. Unlike nonblind methods, blind methods do not require the possession of original content.

In spatial methods, the watermark is inserted directly into the values of samples of multimedia content. Transformation techniques for inserting a watermark are significantly more resistant to malicious attacks than spatial methods, and in particular attempts to remove or replace the watermark in multimedia content. Video content is multimedia information whose protection is considered in this paper. Inserting a watermark can also be performed in an uncompressed and compressed video domain.

Color models of video

Due to its universal application (independent of the selected transformation domain), in this paper, an uncompressed video domain and a hybrid model consisting of YUV and SVD transformations are used to insert a watermark.

Because knowledge of the content of the watermark can be compromising, the watermark is encrypted before being incorporated into multimedia content [5].

Researchers have developed the largest number of methods for inserting a watermark into images that can also be applied to video content. However, due to its specificity with regard to the images, the video provides an expanded possibility of inserting a watermark. Since the video consists of a series of frames (pictures), inserting the same watermark can be done in each frame. In the extraction process, a redundant array of watermarks is available which can be used to repair it [5]. In this paper, the idea of inserting different binary watermarks into different video frames is used. If a watermark decomposition is performed on multiple bit-planes [3], [6] then each plane of decoded watermark can be inserted into different frames. Each bit plane represents a single binary watermark, which together with the other seven make a black and white watermark. Inserting the bit level is repeated cyclically in the next video frames, which ensures redundancy and the ability to repair an extracted watermark. On the receiving side, after the extraction of all bit-planes, the original watermark can be arranged. In this way, the resistance of the inserted black and white watermark is increased, especially in the mobile environment. The basic idea is to make protected video more resistant to packet loss, which is a common phenomenon in the mobile environment [7], [8]. In addition, the resistance of protected video to frame dropping attacks has increased.

Color images can be modeled by different color systems, and most commonly in RGB, CMY and YUV models. The YUV color model is represented by three components: luminance (Y) and two chrominance components (U and V). The statements establish the connection between RGB and YUV components:

$$Y = 0.299R + 0.587G + 0.114B \quad (1)$$

$$U = 0.564(B - Y) \quad (2)$$

$$V = 0.713(R - Y). \quad (3)$$

In this color model, the Y component is a black-and-white image, so that by simply adding chrominance components (U and V) it can be transformed into a color image. In this paper, the binary watermark is inserted into uncompressed video content in the chrominance channel. The idea of inserting into the chrominance channel is inspired by HVS (Human Visual System) and less noticeable degradation of protected video is expected.

SVD decomposition

In the linear algebra SVD (Singular Value Decomposition) [8], [9], [10], [11] is an algorithm for decomposing a rectangular matrix A with dimensions n × m on three matrices:

$$A = U \times S \times V^T \quad (4)$$

where $A \in R^{(n\times m)}$, $U \in R^{(n\times n)}$, $S \in R^{(n\times m)}$ and $V \in R^{(m\times m)}$. Matrices U and V are orthogonal matrices ($UU^T = I, VV^T = I$), and the columns of these matrices are called left singular vectors. The matrix, S is a diagonal matrix, known as the matrix of singular values. If r is the rank of the matrix A, then the elements of the matrix S satisfy the following relation:

$$s_1 \geq s_2 \geq \cdots s_r \geq s_{r+1} = s_{r+2} = \cdots = s_n = 0 \quad (5)$$

then matrix A can be represented as follows:

$$A = \sum_{p=1}^{r} s_p u_p \, v_p^T \quad (6)$$

where u_p and v_p represent the p-th eigenvalues of the matrices U and V, while s_p is p-th singular value. Singular vectors determine the matrix A geometry, while singular values specify the energy (image illumination) of the matrix A. If matrix A presents a single video frame, then a series of similar matrices can represent a video. The most important characteristics of the SVD transformation are the invariance to the transposition, scaling, rotation, and replacement of columns of matrix types A. This method of decomposition of the frame was applied in previous works [5], [6], [7] when watermark was inserted in a frame.

SVD decomposition of small blocks

If we consider a 4×4 pixel matrix representing a small block of video frames, some specificities can be noticed. First, it is assumed that within this block there is no significant change in the illumination of adjacent pixels, which means that the singular values of the matrix will have a good stability even when the pixels are disposed. Although the elements of the matrices U and V can be arbitrarily assigned to SVD decomposition, it is common that the elements of the first column of the matrix U always have the same sign. This is often the source of the problem when using the SVD decomposition [12]. Thus, for example, in the Matlab software package, the same sign assignment in all versions is not retained.

Another important feature of matrix U is that in addition to having all the elements of the first column have the same sign, the difference between them is very small [10]. This conclusion is particularly pronounced in small blocks. The analysis of the elements of the matrix U determined that the smallest difference between the elements $U_{2,1}$ and $U_{3,1}$. This conclusion applies both to blocks belonging to border regions and to blocks belonging to uniform picture regions. This matrix U property is used to insert one bit of watermark into a frame, as it does not cause significant degradation of the original content. To apply this idea, before inserting, the video frame is divided into a series of non-overlapped blocks of 4×4 pixels. It is clear that this method of inserting the watermark has a limitation on the capacity of the inserted bits. When inserting a watermark using standard SVD decomposition on a whole frame this was not the case.

Inserting the watermark in the U matrix is based on modifying the elements $U_{2,1}$ and $U_{3,1}$ to define their mutual relationship. If a positive difference between these elements is created, a logical one is inserted, that is, if a negative difference between these elements is created, the logical zero is inserted. The details of the algorithm for inserting and extracting the watermark will be shown in a separate section.

In this way, the bits that belong to the binary watermark can be effectively inserted into the frame.

Bit-plane watermark decomposition

In this paper, the SVD concept for inserting black and white watermarks above which the bit-plane decomposition was previously executed is used. The following section shows the concept of bit-plane decomposition.

The standard way of storing uncompressed black and white images is in the form of a matrix dimension m × n. The elements of this matrix represent the illumination of each individual pixel of the watermark. The matrix elements in this case are non-negative integers d that can be represented in the binary position with k bits:

$$d = \sum_{l=1}^{k} b_i \, 2^{l-1} \quad (7)$$

For a monochrome image, the pixel values are in the range $0 \le d \le 255$ so that each pixel value can be represented by an 8-bit binary number (k=8). The expression (7) allows decomposition of the black and white image into eight bit-levels. One bit-plane is formed from the corresponding weight bits of all the pixels of the watermark. Thus, i-th bit is formed from the i-bits of all pixels of the stamp. In this way, the required capacity of the insertion method can be reduced. On the other hand, the decomposition of the watermark into several bit-planes allows the insertion of individual bit-planes of the watermark in several video frames. Watermark dissemination in eight video frames will favorably affect the identification of a watermark in the event that some of the frames are lost or degraded. It is also possible to combine multiple bit-planes into a single bit-plane, which can further reduce the insertion capacity [8].

PROPOSED METHODOLOGY

Inserting a watermark in the chrominance video channel - BLIND SVD

Step I_1: Execute the bit-plane decomposition of the black and white watermark $W_{m\times n}$. In order to perform the decomposition of the watermark into eight bit planes, one should first present the values of all the watermark pixels w_i and the corresponding binary values $b_{i,k}$ in the following way:

$$b_{i,k} = \left\lfloor \frac{w_i}{2^{k-1}} \right\rfloor mod\ 2,\ \ k = 1,2,\dots,8; \quad (8)$$
$$i = 1,2,\dots,m\times n$$

In the expression (8) the w_i symbol is represented by the i-th pixel of the black-and-white (grayscale) watermark. The $b_{i,k}$ designation presents the 8 binary binary value of the i-th pixel. The bit plane to the watermark W^k forms from all k bits of all pixels of the watermark.

$$W^k = b_{i,k} \quad (9)$$

Step I_2: The chrominace component U from the uncompressed video frame is divided into non-overlapped blocks $H_{i,j}$ of 4×4 pixels.

Step I_3: For each block $H_{i,j}$ from the U component, perform the SVD decomposition:

$$H_{i,j} = U_{i,j} \times S_{i,j} \times V_{i,j}^T \quad (10)$$

Step I_4: Modify the elements from the second and third columns of the first row of each U(i, j) of the matrix (elements $u_{2,1}$ and $u_{3,1}$) based on the value of each individual bit w from the corresponding bit level as follows:

$$if\ \ w = 1, \begin{cases} u_{2,1}^* = sign(u_{2,1}) \times \left(U_{avg} + \frac{T}{2}\right) \\ u_{3,1}^* = sign(u_{3,1}) \times \left(U_{avg} - \frac{T}{2}\right) \end{cases} \quad (11)$$

$$if\ \ w = 0, \begin{cases} u_{2,1}^* = sign(u_{2,1}) \times \left(U_{avg} - \frac{T}{2}\right) \\ u_{3,1}^* = sign(u_{3,1}) \times \left(U_{avg} + \frac{T}{2}\right) \end{cases} \quad (12)$$

$$U_{avg} = \frac{(|u_{2,1}| + |u_{3,1}|)}{2} \quad (13)$$

where T represents the desired threshold in the difference between the elements $u_{2,1}$ and $u_{3,1}$ of the matrix U(i,j). The modified matrix is denoted by U*(i, j).

Step I_5: Perform an inverse SVD transformation to obtain a watermarked block from the watermark:

$$H_{i,j}^* = U_{i,j}^* \times S_{i,j} \times V_{i,j}^T \quad (14)$$

Step I_6: Repeat steps 4 and 5 for all bits from the appropriate bit plane watermark.

Step I_7: Repeat steps 2 to 6 for all bit watermarks for each next frame. In this way, a video with an embedded watermark is obtained. For the extraction of the watermark thus inserted, it is not necessary to have the originals of either the video or the watermark, so this algorithm belongs to the class of blind algorithms.

Watermark extraction from a chrominance video channel

Step E_1: The U component of the protected frame should be divided into non-overlapped blocks $H'_{i,j}$ of dimensions 4 × 4 pixels.

Step E_2: Perform the SVD decomposition of all the blocks $H'_{i,j}$ from the frame.

$$H'_{i,j} = U'_{i,j} \times S'_{i,j} \times V'^T_{i,j} \quad (15)$$

Step E$_3$: The value of the corresponding extracted bit of the watermark w' is obtained using the following terms:

$$w' = 1, \begin{cases} 0, \ if\ u'_{2,1} > u'_{3,1} \\ 1, \ if\ u'_{2,1} \le u'_{3,1} \end{cases} \quad (16)$$

Step E$_4$: Repeat steps 2 and 3 for all non-overlapping blocks of the frame.

Step E$_5$: Create a binary image of the corresponding bit-plane watermark.

Step E$_6$: Repeat steps 1-5 for eight frames from the video.

Step E$_7$: With all the 8 binary bit-planes, form a black and white watermark.

Step E$_8$: Repeat steps 1-7 for all frames from the video.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 1a) shows the black and white watermark used in the experimental part. The watermark is an adapted central part of the famous black and white *Lena.bmp* image at a resolution of 36×36 pixels. This watermark was inserted into the also well-adapted famous *Foreman.yuv* video color at a resolution of 288×288 pixels. As described in the previous section, the insertion algorithm requires the decomposition of the watermark into eight bit-levels. Figure 1b) shows the prospects of all eight bit-planes. From the picture, it can be noticed that the MSB bit plane has significant information that affects the watermark's recognition.

If the obtained bit levels are observed, it can be noticed that as we approach the LSB bit level, decomposition of the watermark takes on a stochastic character. This is why there is no additional protection of the watermark in this paper, as the authors did in previous works.

Bit-plane decomposition of the watermark were incorporated in the first 96 frames of the Foreman.yuv video. In the first frame, the MSB pit-plane was built, in the second frame, the 7-th bit plane, and so on. In the eighth video frame, the LSB Bit-plane watermark is embedded. In addition, the MSB Bit-plane was inserted in the 9-th frame and so on. In the 96-th frame of the video, the LSB bit plane is installed, so the entire video is protected. The insertion of watermark components according to the considered algorithm is done in the chrominant components of the frame with threshold T=0.04, as was done in most published works.

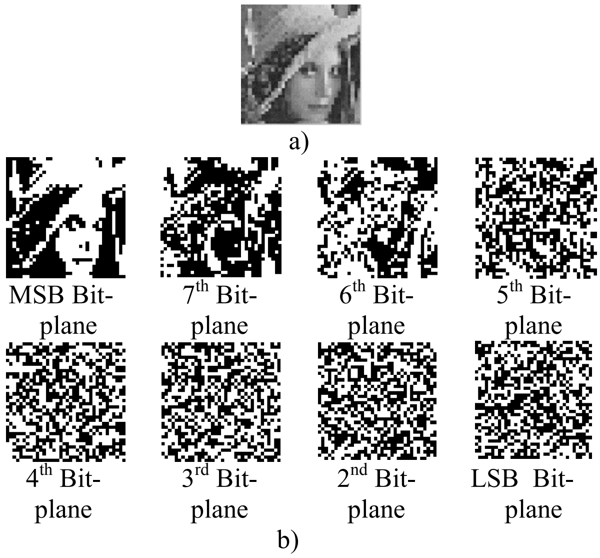

Fig. 1. *Watermark a) Gray-scale original b) All 8 bit-planes of watermark from MSB to LSB planes*

All the components of the watermarked 30-th frame of *Foreman.yuv* are shown in Fig. 2. In Figure 2a), the Y component of the .yuv format is displayed which is unchanged and is equal to the original. In Figure 2b) and 2c) the chromanent components of this format are shown. In Fig. 2b), U is a component of the protected 30th frame in which the corresponding bit-plane component of the watermark is inserted. In the shown case, a 3-bit bit-plane component is inserted. Insertion was done in the SVD domain as described in the previous section.

Unlike the DWT MSB algorithm, the BLIND SVD algorithm recommended in this paper does not require knowledge of the original content. This is considered its advantage over the DWT MSB algorithm.

Fig. 2. *Protected frame number 30 from the video shown in .yuv format a) Y component b) The U component in which the 3-rd bit plane of the watermark is inserted c) V component*

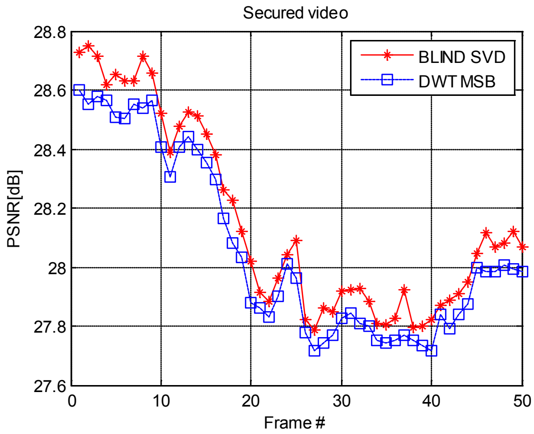

***Fig. 3**. The quality of the first 50 frames of protected video "Foreman" using the algorithm from [7] denoted DWT MSB and the proposed algorithm designated with BLIND SVD*

The protected video sequence is compressed by the JM reference software of ITU in version 18.4 FRExt. The coding quality is defined by a set of FRExt parameters. The following key parameters have the key influence on the selection of the quality of the encoding: IntraPeriod = 12, NumberReferenceFrames = 5, NumberBFrames = 1.

The quality of the extracted watermark was SSIM=0.7288 of the applied DWT MSB algorithm, while the recommended BLIND SVD algorithm was realized by SSIM=0.8466. The proposed algorithm provides better quality of the extracted watermark by about 18%, which favors it in future video protection applications. Fig. 3 shows the PSNR for the first 50 protected foreman video frames. The realized PSNR is shown for both methods under consideration.

Based on these values, it can be concluded that the extracted watermark can be successfully used to protect the video.

CONCLUSION

Protecting video content is a necessary activity before exposure on the Internet. Inserting a watermark into video content is considerably safer than conventional encryption technologies. The advantage over conventional technologies is in the fact that the watermark protects video content even after playback. In this paper, all components of watermarks are inserted into the corresponding frame video. Inserting watermarks with the BLIND SVD algorithm is done by the chrominance component of the video using HVS so that the resulting artifacts are imperceptible. The quality of the protected video is very good, while the high quality watermark is extracted at the same time. The results obtained by the simulation confirm that the proposed algorithm can be efficiently used to protect video content.

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