An Efficient Group of Pictures Decomposition based Watermarking for Anaglyph 3D Video

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Abstract: Due to the rapid grow of 3D technology, 3D video consumption over the internet is proliferated. 3D Content protection has then become an important challenging problem for many researchers. Watermarking allows resolving this problem by embedding a signature into 3D video content. However, only a few works are proposed for 3D anaglyph content protection. In this paper, a new approach of 3D video anaglyph watermarking is proposed. In fact, the anaglyph 3D technique is considered as the best used technique for creating 3D perception for both images and videos. The proposed approach is based on GOP decomposition where original video is considered as a set of Group of pictures (GOP). Each GOP will be divided in three types of images: only one reference image and several B and R images. Then, every type of images will be marked using a different algorithm based on blue, red or depth channel. This allows to benefit from advantage of every channel. Experimental results show a high level of invisibility of the proposed approach and a robustness against several attacks such as compression, noise, filtering, frame suppression, and geometric transformations.

1 INTRODUCTION

Thanks to the availability of 3D TVs, the high-speed Internet access and the progression of 3D technology, the popularity of 3D videos increases daily. Indeed, 3D video is getting an enormous public attention recently because of vivid stereo visual experience over 2D video. There are several ways and techniques to perceive videos in 3D such as the polarized light system and the active shutter system. Despite the advantages of these two techniques, they present a main drawback which is the hardware requirement. In fact, the active shutter system requires a special display with an alternate liquid crystal shutter glasses which is too expensive because of the needed electronic device while in the case of the polarized system, a polarized display is needed such the pairs of polarized filter glasses which are also very expensive. Another display mode for 3D videos that has taken the attention of researchers is the anaglyph mode. In fact, an anaglyph 3D image consists of two superimposed images (called homologues) of complementary colors representing the same scene but seen from slightly offset points : usually the left view in red and the right view in cyan. It is a printed image to be seen in relief, using two filters of different colors (3D glasses) placed in front of each eye of the observer. Anaglyph 3D images contain two filtered colored images (red and cyan), one for each eye. The anaglyphic processing is the cheapest and the most simple way to make the 3D visual experience accomplishable on ordinary monitors without any special hardware needed, just only colored glasses.

Due to the quick development of the 3D multimedia technology, the transmission of 3D video content over the internet became very easy. However, this content cannot be distributed illegally without any protection. For produced views generated from a depth image-based rendering technique, the left and right views can be distributed as a 3D content and also, the center, the left and right views, can be distributed separately as a 2D content. Protecting these views from unauthorized distribution becomes a very significant and important issue. Watermarking technique presents an effective solution for this problem because it provides security and copyright protection to digital data. Indeed, it consists to insert a robust and invisible signature into an original 3D video then to try to detect the presence of the embedded signature after any attack applied on marked content.

Several 2D video watermarking works have been proposed in the literature but regarding 3D videos, the

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field is still not mature given the diversity of display models and the complexity of 3D data. Most of the techniques that have been proposed for 3D video watermarking consider 3D video as a set of video views plus a rendered depth image (Multi view Video plus Depth MVD). Hence, they insert the signature into this Depth Image Based Rendering (DIBR) using a still image embedding scheme (Asikuzzaman et al., 2016) (Rana and Sur, 2015).

Concerning 3D anaglyph video, only few works are proposed and they didn't maximize the compromise invisibility / robustness. In order to resolve this problem, we propose in this paper a new robust approach of 3D anaglyph video based on GOP decomposition in which, the original video is considered as a set of GOP. Each GOP will be divided into three image types : one reference image I, R, and B images. The reference image will be marked using a depth based embedding, R image will be marked using a red channel based embedding and B image using a blue channel based scheme. This allows benefiting from the robustness of every emebedding scheme. In order to maximize the invisibility of the proposed approach, the GOP will contain B images more than R images because the eye is less sensitive to the blue channel.

The remaining of this paper is organized as follows: the next section presents a state of the art of anaglyph 3D images and 3D videos watermarking schemes. Section 3 deals with the different steps of the proposed approach of anaglyph 3D video watermarking based on GOP. Section 4 evaluates the performance of the proposed method by giving the experimental results. Finally, a conclusion and some perspectives are drawn.

2 STATE OF THE ART

An anaglyph 3D video can be considered as a sequence of anaglyph 3D images. Hence, an anaglyph 3D video watermarking scheme can apply an anaglyph 3D image technique into images which compose the 3D video. For this reason, we begun by studying the existing watermarking techniques proposed for 3D anaglyph images.

2.1 Overview of Anaglyph 3D Image Watermarking

The existing approaches proposed for anaglyph 3D images can be classified according to two criteria: the chosen channel for the embedding and the used transformation.

Based on the first criteria, signature can be embedded into one of the two pairs of stereo images using a 2D embedding scheme. The watermarked image will then be combined with the other views in order to obtain the marked anaglyph 3D image. We have noted that in the most of the proposed works, authors insert the signature in the blue image because the human eye is less sensitive to the blue color. This allows obtainning a high level of invisibility but it decreases the robustness (Prathap and Anitha, 2014).

(Patel and Bhatt, 2015) propose a watermarking scheme based on Wavelets where the signature is inserted into the blue image (right view). The obtained marked blue image is then combined with the original red image (left view) to obtain a marked anaglyph 3D image. For signature extraction, an inverse deanaglyph process is used to separate the two stereoscopic images and the signature is extracted from blue image. This method has proven a high level of invisibility but it is not robust to the majority of attacks. Another watermarking technique is proposed in (Zadokar and Rathod, 2015) and (Zadokar et al., 2013) where the mark is embedded into the three images composing the anaglyph 3D image : red (left view), blue (right view), and depth image. This technique offers a better robustness against different attacks and high invisibility.

Concerning the used transformation, we have noted that the most of the proposed works are mainly based on the Wavelet Transformation to embed signature in the anaglyph 3D images by modifying the high frequencies in order to maximize the invisibility and robustness compromise (Patel and Bhatt, 2015), (Zadokar et al., 2013).

In (Prathap and Anitha, 2014) a simple scheme for the protection of 3D red-cyan anaglyph images based on 3D-DWT and the Jacket matrix is proposed. In this approach, the original image is transformed using multi-level 3D-DWT and the middle level sub-bands are divided into blocks. Next, the Jacket matrix is applied to the middle level sub-band blocks and the signature is embedded by modifying the diagonal elements of each block. This method is robust against several attacks thanks to the use of the decomposition level of 3D-DWT, the block size, the minimum value of middle level sub-bands and the watermark strength factor. In addition, it is a blind watermarking scheme that does not require the original image during the extraction process. Therefore, this method has a good invisibility with a PSNR value greater than 51 dB.

(Devi et al., 2016) proposed a robust and optimized blind encrypted three dimensional red-cyan anaglyph image watermarking system. In fact, the proposed approach comprises two phases: trainning phase and testing phase. In the training phase, the original red-cyan anaglyph cover image is decomposed applying Discrete Wavelet Transform (DWT) to get the low and high pass filter values. The DWT transformed bits (LH and HL) are optimized using genetic algorithm (GA) and are trained using Back Propagation neural Network (BPN). During the testing phase, a binary image with a size of 32×32 is embedded after applying the Advanced Encryption Standard (AES) encryption method into the three dimensional anaglyph image by adding it to the optimized transformed bits. Finally, the extraction of the embedded image is done by finding the Eigen feature vectors that give the characteristic values for the extraction of the watermarked image.

(Munoz-Ramirez et al., 2015) propose to embed the signature into the frequency domain using the Discrete Cosine Transform (DCT) and quantization of index modulation (QIM) with its variant Dither Modulation (DM). (Rakesh and Dr.K.Sri Rama, 2016) proposed a watermarking algorithm for anaglyph 3D images based on the Fourier Fractional Transform (FrFT). In this approach, the watermark is embedded into the right image (blue channel) of the anaglyph 3D image after applying the 2-D FrFT transformation. Then, the watermarked right image and left image are combined to obtain the marked anaglyph 3D image. At extraction step, the signature is detected by calculating the threshold and comparing it with the detection value.

(Wang et al., 2015) proposed two 3D watermarking scheme for 3D anaglyph image. The first one uses Spread Spectrum (SS) technology to embed signature while the second is based on adaptive Dither Modulation (DM) with Watsons improved perception model. The two schemes present a robustness against several attacks and a high level of invisibility.

An other blind three-dimensional anaglyph image watermarking scheme for copyright protection is proposed in (Devi and Singh, 2017) where the N-level nonsubsampled contourlet transform and the Principal Component Analysis (PCA) are used to embedd signature. In fact, The binary watermark is encrypted using Arnold transform. Then, it is embedded into the selected sub-band of the nonsubsampled contourlet-transformed anaglyph 3D image using the principal component analysis.

2.2 Overview of 3D Anaglyph Video Watermarking

Based on our knowledge, there are only two existing works proposed for anaglyph 3D videos watermarking until now. Indeed, the first work (Waleed et al., 2013) is based on RGB color analysis where the signature is inserted in all the blue channels of all frames composing the original anaglyph 3D video using the Discret Wavelet Transform (DWT). The blue channel is chosen because the blue color variation is hardly perceived by the human visual system. For this approach, a 4-level Discrete Wavelet Transform is performed to the blue channel and the signature is embedded in the high frequency bands (HH) of that channel. The detection step is blind and didn't require the original signature or the original video during the extraction process.

The second scheme is a blind and invisible watermarking technique based on scenes change detection. Since human eye is less sensitive to blue color, the signature bits are inserted into the high frequency bands (HH) of the blue channel of the anaglyph frames where a scene change is detected (Salih et al., 2015).

Despite the advantages of these two proposed approaches, they are not robust against the most important video attacks. In fact, the insertion of mark only in the blue images forming the video causes a lack of robustness if the attack targets the blue images of the video then the signature will be easily lost. Hence, an insertion in the different views of the anaglyph image is necessary to obtain a high level of robustness. Moreover, if the signature is inserted only in scenes change frames, a fragile watermarking can be obtained in the case of videos presenting a single or a small number of scenes.

Table 1: Comparison of the existing approaches.

Proposed works	Method	Invisivility	Robustness
(Prathap and Anitha, 2014)	image	+ (51 dB)	JPEG compression, Filtering, Noise, Geometric attacks, Contrast adjustment, Color quantization.
(Devi et al., 2016)	image	+ (53 dB)	Filtering, Noise, Geometric attacks, Blurring, Histogram Equalization, Color quatization, Gamma correction.
(Munoz-Ramirez et al., 2015)	image	+ (40 dB)	JPEG compression, Noise.
(Rakesh and Dr.K.Sri Rama, 2016)	image	- (27 dB)	Not mentioned
(Wang et al., 2015)	image	+ (41 dB)	Noise, Shrinking, Filtering, cutting, JPEG compression, Luminance change, Volumetric scaling.
(Devi and Singh, 2017)	image	++ (69 dB)	Filtering, Noise, Geometric attacks, Blurring, Histogram Equalization, Color quantization, Gamma correction, Contrast adjustment.
(Waleed et al., 2013)	video	++ (65 dB)	Noise, Cropping, Filtering, Gamma correlation, Intensity Adjustment,
(Salih et al., 2015)	video	++ (69 dB)	Histogram equalization, JPEG compression.

In table 1, the existing approaches are compared based on the most important criteria: invisibility and robustness. We can observe that the majority of the existing approaches guarantee a high level of invisibility however they don't resist against the most important attacks such as MPEG compression and frames suppression. Moreover, All the existing approaches didn't evaluate the combination of manipulations which is an important attack to assess any video watermarking approach.

3 PROPOSED ANAGLYPH 3D VIDEO WATERMARKING APPROACH

In order to avoid all the disadvantages of the existing techniques, a new approach of 3D anaglyph video watermarking based on GOP decomposition is proposed in this paper. There are two main steps in this scheme: GOP decomposition and signature embedding.

Giving an original 3D anaglyph video, it will be decomposed in different Groups of Pictures (GOP). Then, each GOP will be divided in three types of images : reference image that we called I, Blue and Red images that we called respectively B and R. Every type of images will be marked using a different embedding algorithm in order to maximize the robustness of the proposed approach. Indeed, B images will be marked using a scheme which modify only blue channel, R images will be marked by modifying only red channel and finally I image will be marked by modifying all of red, blue channels in addition of the depth image. Hence, if any attack removes one type of images, the detection algorithm will be able to extract signature from the other types of images. Moreover, in order to increase the invisibility of the proposed scheme, the GOP must contain a larger number of B images because the human eye is less sensitive to the blue channel. Embedding process will be based on Discrete Wavelet Transform (DWT), which allows obtainning robustness against usual attacks.

The general watermarking scheme consists then of the following steps :

1. Divide the original anaglyph 3D video into a set of GOP.
2. Divide each GOP into three types of images : I, B and R images.
3. Repeat the embedding stages for every GOP:
   (a) Embed the signature into the blue and red channels in addition of the depth image generated from I image.
   (b) Embed the signature into the blue channel of B images.
   (c) Embed the signature into the red channel of R images.
4. Combine the marked channels of each type of images with their complementary original channels to obtain the marked anaglyph 3D images.
5. Combine all marked GOP in order to generate the marked anaglyph 3D video.

Basic building block of the proposed approach is shown in the Figure 1.

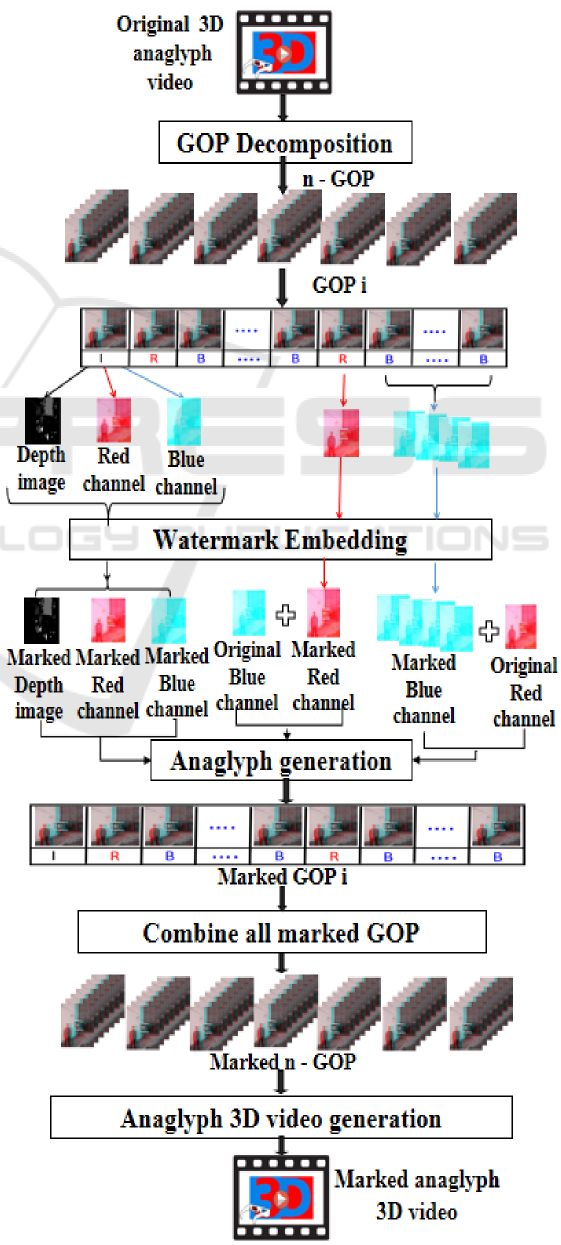

Figure 1: The general layout of the proposed approach.

3.1 GOP Decomposition

In order to guarantee a high level of robustness against attacks and especially against MPEG compression and frames suppression attacks, the first step of the proposed approach consists in decomposing the original anaglyph 3D video into a set of Group of Pictures (GOP). Indeed, several existing video watermarking techniques are based on GOP decomposition which is used in MPEG compression process. In (Liu and Zhao, 2010), a watermarking algorithm based on GOP decomposition was proposed. In fact, the original 2D video sequence is divided into GOP. Then, the signature is embedding in the coefficients obatained after applying the 1D DFT transformation on each GOP in order to improve the robustness of the algorithm. In (Liu et al., 2008) a real-time video watermarking scheme is presented by embedding the watermark bits both in I and P frames based on GOP decomposition. An uncompressed video watermarking system based on Hidden Markov Model (HMM) and Artificial Neural Network (ANN) is proposed in (ELBAŞI, 2010). In fact, the proposed scheme splits the video sequences into GOP with HMM. Then, Portions of the binary watermark are embedded into each GOP with a wavelet domain watermarking algorithm. The embedding process is the standard additive algorithm in low pass (LL) and high pass (HH) bands in the wavelet domain. This proposed system increases the robustness against geometric and temporal attacks, and increases the quality of the marked video.

In order to choice the GOP size for the proposed approach, we consider that it is difficult to have large changes in a video sequence after one second. Hence, we choose one GOP per one second. Then, each GOP is divided into three types of images : I, B and R images. As the I image will be marked with a depth based scheme, one only reference image is selected per one GOP in order to guarantee a high invisibility. In addition, the number of B images should be superior to R images because B images will be marked by modifying blue channel which is the less sensitive for a human eye. Each GOP is then composed of a single reference image I, two R images and the rest will be considered as B images.

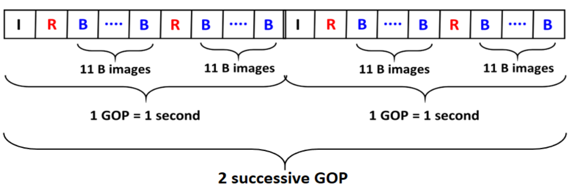

Figure 2: GOP decomposition.

For the selected test videos, we have about 25 frames per second. Hence, each GOP will begin by one I image followed by two identical parts each containing one R image and 11 successive B images as shown in Figure 2.

3.2 Signature Embedding

In order to increase the robustness and the invisibility of the proposed approach, a DWT based scheme is chosen. Figure 3 shows the general architecture of the signature embedding process which is decomposed in several steps. Indeed, to embed the signature, a three levels of wavelet decomposition are applied on the different images of each GOP using the Haar filter wavelet which is known for its simplicity and speed of computation (Zhang, 2009) (Zheng et al., 2007). DWT transformation will be applied on respectively blue and red channels for B and R images while for the reference image, DWT will be applied on its depth image and both blue and red channels. For each image, the watermark information is embedded by adding the signature to the low frequency sub-band (LL3) of each image in order to increase the robustness of the signature, since it is the most significant band, which contains more information and includes the most energy of the image rather than the others bands which include edge components of horizontal, vertical and diagonal directions. The marked images will be obtained by applying the inverse DWT to the marked sub-bands. Finally, the marked B and R images are obtained by combining respectively the corresponding original red and blue channels with the marked blue and red channels. The marked reference image will be obtained by combining marked red and blue channels with the depth image.

Given an original anaglyph 3D video, the signature embedding procedure consists then of the following steps :

1. Apply a three levels of wavelet decomposition to the original channel.
2. Apply a three levels of wavelet decomposition to the signature.
3. Add the coefficients of the low frequency band of the signature (CW_i) to those of the original channel (C_i) using an invisibility factor (α) to obtain the marked coefficients (C_i)$\prime$ according to the following equation :

$$C_i\prime = C_i + \alpha * CW_i \qquad (1)$$

4. Apply the inverse decomposition wavelet transform (I-DWT) to generate the marked channel.

5. Combine the marked channel to the other channels in order to obtain anaglyph 3D marked image.
6. Combine all marked anaglyph 3D images to generate the marked anaglyph 3D video.

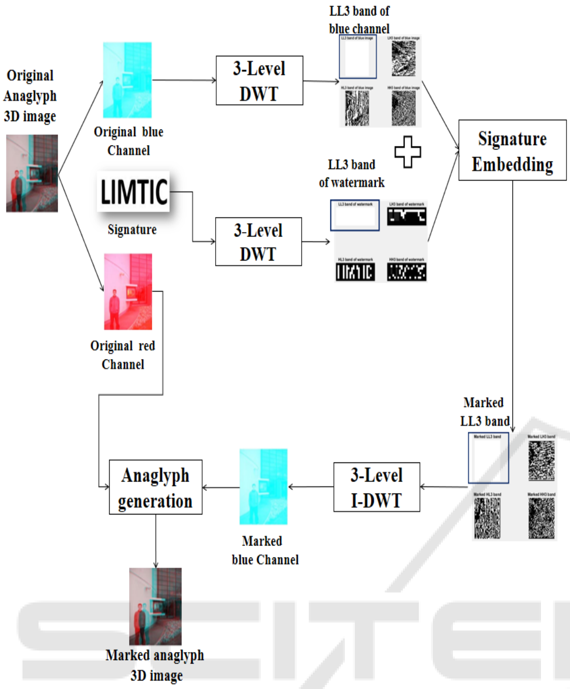

Figure 3: Layout of the embedding process.

3.3 Extraction Process

The general detection scheme is decomposed in several steps where the two first ones are identical to those of the embedding scheme.

In fact, given a marked anaglyph 3D video, it will be decomposed in several GOP with the same frame number chosen at embedding phase. Then, R, B and reference images will be detected for every GOP. For each type of image, the inverse embedding process will be applied on the corresponding channel in which the signature was embedded.

Given an input anaglyph 3D video, the extraction algorithm consists of the following steps:

1. Divide the given video into several GOP.
2. Apply the 3-levels DWT to the different channels as done in embedding process.
3. Extract the coefficients of the signature from the low frequency band (LL3) channels.
4. Apply the inverse decomposition wavelet transform (I-DWT) to recover the watermark.

4 EXPERIMENTAL RESULTS

In order to evaluate the proposed approach, a set of robustness and invisibility tests are applied on a database containing five original anaglyph 3D videos having different characteristics of background texture, movement, resolution and frame number.

Table 2 shows the characteristics of the chosen videos. Moreover, for a same video, we have tested different sizes in order to evaluate the GOP size choice.

Table 2: Video test characteristics.

Videos	**Frame number**	**Resolution**	**Background Texture**	**Movement**
Video 1	250	480×360	Uniform	Slow
Video 2	750	480×360	Uniform	Slow
Video 3	1500	640×180	Textured	Medium
Video 4	2250	1280×720	Textured	Rapid
Video 5	3000	480×360	Uniform	Slow

Three different binary images (Lab Logo, Lab name and Author name) with different sizes (245×140, 160×50 and 80×25) are used as signatures (Figure 4).

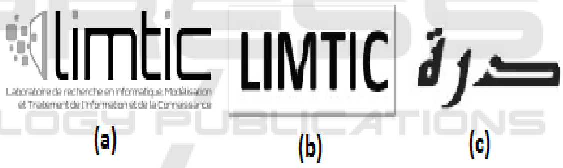

Figure 4: Original watermarks: (a) Lab logo, (b) Lab name, (c) Author name.

4.1 Invisibility Evaluation

Figure 5 presents embedding results. No differences can be observed between the original and marked videos.

In order to prove this high level of invisibility, the average of the PSNR (Peak Signal to Noise Ratio) between original and marked frames is calculated. Generally, a good invisibility is marked with a PSNR superior to 40 dB.

Table 3 presents the obtained PSNR values for test videos using the different signatures. These values show that the proposed watermarking has a high invisibility. In fact, the minimum PSNR is about 69 dB and its maximum is about 72 dB.

Moreover, we evaluated the impact of video size variation on the PSNR value in order to test the invisibility of the proposed approach. Obtained results are shown in Figure 6 which prove that even by increa-

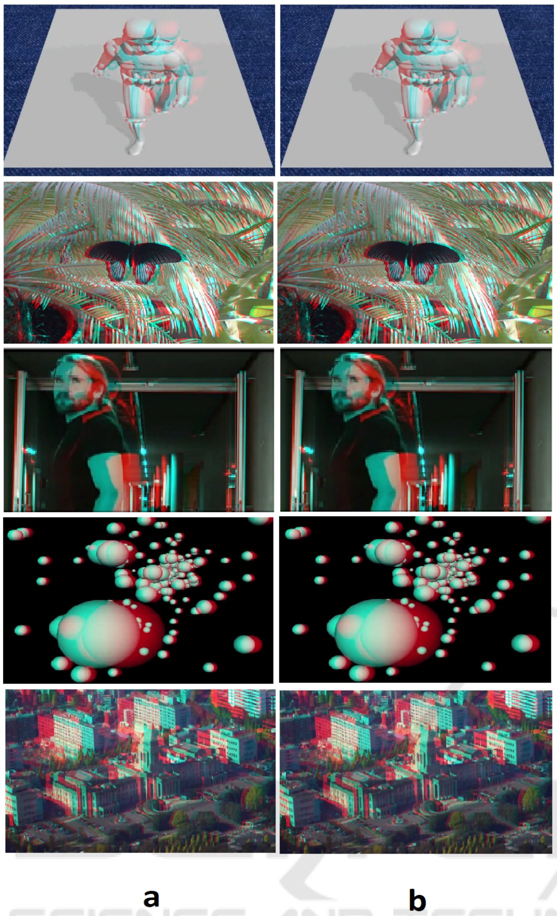

Figure 5: a- Original anaglyph frame. b- Watermarked anaglyph frame.

Table 3: PSNR values of test videos.

Watermarked video sequences	Watermark	PSNR
Video 1	(a)	70.99
	(b)	71.90
	(c)	72.91
Video 2	(a)	70.93
	(b)	71.82
	(c)	71.89
Video 3	(a)	70.89
	(b)	71.32
	(c)	71.64
Video 4	(a)	70.77
	(b)	70.68
	(c)	70.56
Video 5	(a)	70.65
	(b)	70.52
	(c)	69.95

sing the size of the test video, the visual quality of the marked video does not degrade.

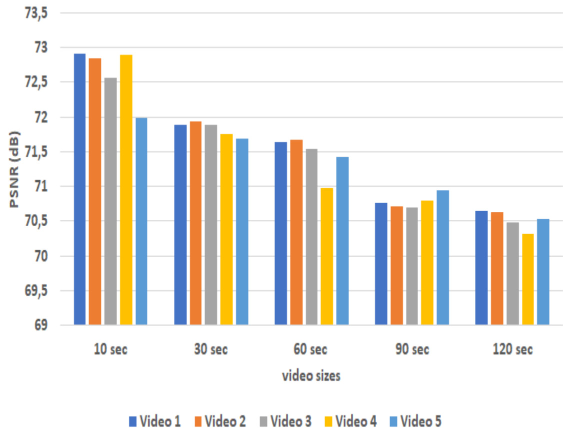

Figure 6: Influence of invisibility based on video size.

4.2 Robustness Evaluation

To evaluate the robustness of the proposed approach, different unintentional and malicious attacks are tested. These attacks were applied directly to the marked video. The Normalized Correlation value (NC) and the Bit Error Rate (BER) are measured between the original and the extracted marks in order to decide the result of robustness against an attack.

In order to evaluate robustness against unintentional manipulations, geometric attacks are firstly tested as; cropping, rotation with various angles, scaling, and resizing. Also some noises and filters were applied to the marked video and then we try to detect the signature and calculate the BER and the Correlation between extracted and original mark. Obtained results of the Correlations values of the different test anaglyph 3D videos without attacks and after attacks are shown in Table 4.

The proposed approach is robust to cropping, thanks to the repetition of the mark in all the frames. The robustness against rotation, scaling and cropping is obtained thanks to the use of DWT transformation, which is invariant to these attacks.

The proposed technique is also robust against different noises such as salt and pepper, Gaussian, Poisson and Speckle, filters (Average and Gaussian filter) and blurring where the BER was almost about 0.001 with a correlation about 0.9 almost times. This robustness was enhanced thanks to the invariance of the used DWT transformation.

In second part, temporal attacks are tested by applying given transformation to the marked video as deleting some frames and changing the frames orders from the marked video.

In addition, we have tested frames transposition and dropping until 70% into the same scene. We have noted that the detection succeeds after all these at-

Table 4: Correlation values of different test videos after attacks.

Attacks	Video 1	Video 2	Video 3	Video 4	Video 5
Salt & Pepper noise 0.1	0.9997	0.9995	0.9998	0.9996	0.9994
Gaussian noise	0.9999	0.9998	0.9999	0.9997	0.9996
Poisson noise	0.9997	0.9997	0.9996	0.9998	0.9995
Speckle noise	0.9997	0.9998	0.9997	0.9995	0.9997
Average Filter	0.9992	0.9994	0.9993	0.9994	0.9991
Gaussian Filter 9x9	0.9987	0.9979	0.9969	0.9990	0.9989
Blurring	0.9998	0.9999	0.9996	0.9997	0.9995
Rotation (50%)	09996	0.9995	0.9997	0.9998	0.9993
Rotation (180%)	0.9958	0.9945	0.9961	0.9939	0.9986
Cropping (50%)	0.9999	0.9996	0.9994	0.9996	0.9999
Scaling	0.9998	0.9996	0.9999	0.9997	0.9999
Frame suppression	0.9993	0.9994	0.9995	0.9994	0.9992
Frame swapping	0.9998	0.9997	0.9998	0.9994	0.9996
Resizing	0.9995	0.9993	0.9997	0.9996	0.9994
Histogram equalization	0.9998	0.9995	0.9996	0.9997	0.9995
MPEG compression	0.9999	0.9998	0.9999	0.9999	0.9997
Intensity adjustment	1	0.9978	0.9987	0.9991	0.9999
No attacks	1	1	1	1	1

tacks. This is obtained thanks to the repetition of the signature embedding in different GOP. This fact increases the percentage of detection success even if a part of the sequence is missed or destroyed.

Moreover, Our scheme can withstand various other attacks such as histogram equalization and Intensity adjustment.

Then, the proposed scheme is evaluated against the common video compression standards with bit rate changing. To simulate real cases the mediacoder (http://www.mediacoderhq.com) software application was adapted to transcode the marked video. In fact, this transcoder uses different video codecs to transcode the media to various formats. We have tested the MPEG-4 codec with a variable bit rate. Obtained results show the robustness against compression where the BER was close to 0.0002 and the corresponding correlation close to 0.99. The mark detection is achieved by using the GOP decomposition on which is based the MPEG compression. We have also tested some combination of attacks such as rotation with noise, filtering with geometric attacks and frame suppression combined with geometric attacks. We observe that the signature can be detected after these manipulations which are considered as an important attacks for any video watermarking.

Finally, we noted that the proposed approach is robust against any manipulation which can attack either only blue or red channel. This is obtained thanks to embedding the signature in different channels of the frames.

Figure 7 illustrates the mean BER value of the different anaglyph 3D video samples without attacks and after attacks.

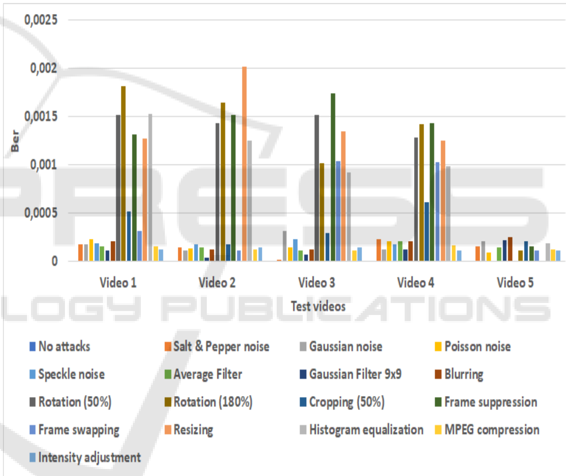

Figure 7: The mean BER value of different test videos.

4.3 Comparative Study

In order to assess the proposed approach, obtained results are compared with those of existing methods. Since there exist only two anaglyph 3D video watermarking schemes (Salih et al., 2015) and (Waleed et al., 2013), we use these two techniques for the comparison. This last one is based on the two main factors: invisibility and robustness.

4.3.1 Invisibility Comparison

Figure 8 illustrates the obtained PSNR values by the proposed approach and the two existing techniques in (Salih et al., 2015) and (Waleed et al., 2013) and it shows the high quality of our proposal.

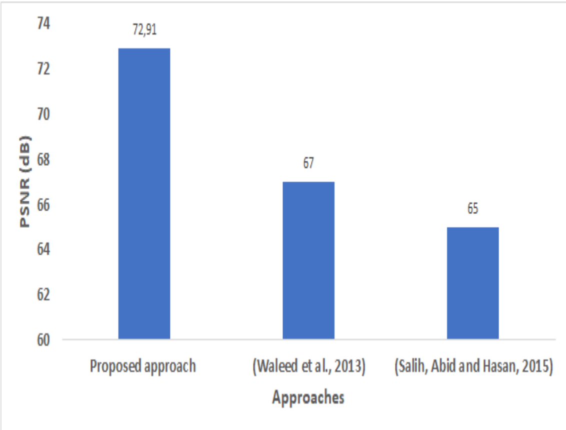

Figure 8: Invisibility comparison based on PSNR criteria.

In spite of the high visual quality of the existing approaches, the proposed scheme allows the best invisibility rate where the PSNR is around 73 dB.

4.3.2 Robustness Comparison

To compare the robustness of the proposed technique with existing approaches, we have distinguished two categories of attacks: usual attacks as geometrics, noises, filtering, scaling and developed attacks as compression, frame suppression, and combined attacks.

The proposed technique shows a good robustness against these two types of attacks. However, a comparison of obtained results with previous techniques is important to assess the proposed approach.

Table 5 resumes the robustness of each technique. The proposed technique shows robustness to almost of attacks whereas other techniques have some limits. Considering usual attacks, the proposed technique has the best robustness to filter attacks. In fact, it is robust to Gaussian, average filter whereas (Salih et al., 2015) and (Waleed et al., 2013) resist only to Gaussian filter.

Proposed approach has the best robustness against noises such as Salt and Pepper , Gaussian, Poisson and Speckle noise where the NC and the BER were almost equal to 1 and 0 respectively. For (Salih et al., 2015) and (Waleed et al., 2013), the NC is close to 0.9.

For geometric attacks, the proposed scheme and the two existing schemes are robust to rotation, cropping and resizing attacks with NC value equal to 0.9.

The proposed technique is robust to frame based attacks as frame suppression and frame swapping thanks to the embedding in all the video frames. The proposed technique shows the best robustness against MPEG compression whereas (Salih et al., 2015) and (Waleed et al., 2013) are robust only to JPEG compression.

Table 5: Robustness comparison between the proposed approach and the two existing techniques.

Attacks	Proposed approach	(Salih et al., 2015)	(Waleed et al., 2013)
Salt & Pepper noise 0.1	Robust	Robust	Robust
Gaussian noise	Robust	Robust	Robust
Poisson noise	Robust	Not Robust	Not Robust
Speckle noise	Robust	Not Robust	Not Robust
Average Filter	Robust	Robust	Robust
Gaussian Filter 9x9	Robust	Robust	Robust
Blurring	Robust	Robust	Robust
Rotation (50%)	Robust	Robust	Robust
Rotation (180%)	Robust	Robust	Robust
Cropping (50%)	Robust	Robust	Robust
Scaling	Robust	Robust	Robust
Frame suppression	Robust	Not Robust	Not Robust
Frame swapping	Robust	Not Robust	Not Robust
Resizing	Robust	Robust	Robust
Histogram equalization	Robust	Robust	Robust
JPEG compression	Robust	Robust	Robust
MPEG compression	Robust	Not Robust	Not Robust
Intensity adjustment	Robust	Robust	Robust
Combined attacks	Robust	Not tested	Not tested
No attacks	Robust	Robust	Robust

5 CONCLUSION

With the development of digital image and video processing, anaglyph 3D images and videos consumption over the internet is proliferated. To protect this type of 3D video, a robust and invisible anaglyph 3D video watermarking approach based on GOP decomposition and a Discrete Wavelet Transformation is proposed in this paper. In this approach, the original video is decomposed to several GOP which are then divided in reference, B and R images. Every type of images was marked using a different embedding scheme. In fact, reference image was marked by modifying its corresponding depth image and both red and blue channels; R images were marked by modifying its red channel and finally, signature was embedded in B images by modifying its blue channel. This allows maximizing the robustness of our approach and obtaining a high level of invisibility. In order to maximize the performance of our approach, we choose 25 frames by GOP (1 second = 1 GOP) and for each GOP we selected the first image as a reference image, 2 R images and the rest will be considered as B images because the human eye is less sensitive to the blue color. Experimentations show that the proposed approach is robust against several attacks such as geometric attacks, frame suppression, compression, noises and filtering with a high visual quality level. In addition, The comparison of the proposed approach with existing techniques shows the good performance of the proposed scheme to resist almost attacks types with a good invisibility.

As future work, we will try to enhance the proposed approach in order to be robust against other intentional attacks and especially against collusion and camcording.

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