Robust Digital Watermarking Scheme of Anaglyphic 3D for RGB Color Images

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Abstract

In this paper, digital watermarking technique using spread spectrum (SS) technology and adaptive DM (dither modulation) with the improved Watson perception model are applied for copyright protection of anaglyphic 3D images. The improved Watson perception model can well solve the problem that the slack do not change linearly as the amplitude scale. Experimental results show that the watermarking schemes provide resistance to Gaussian noise, salt and pepper noise, JPEG compression, constant luminance change and valumetric scaling; the scheme employing improved Watson perception model is better than the one using unimproved Watson perception model. Compared experiments with the works [4] and [19] were also carried out in experiments. On the other hand, the approach is not sensitive to the JPEG compression while the other based on QIM is not sensitive to constant luminance change and valumetric scaling.

Keywords: Digital Watermarking, RGB, Anaglyphic 3D Images, Spread Spectrum (SS) Watermarking Technique, Quantization Index Modulation (QIM), Robust Watermarking.

1. INTRODUCTION

The digitization, storage, transmission and reproduction of multimedia resources have become very convenient. However, the accompanying piracy problem emerges increasingly. Therefore, digital watermarking technology is used to address this issue effectively at home and abroad.

Spread spectrum (SS) technology in the 1950s originated in the communication system, and first used for military communications. It has the advantages of anti-interference, confidentiality, low density of power spectrum and high-precision measurement, so digital watermarking technology employing the spread spectrum principle has high robustness and security. The first digital watermarking algorithm (NEC algorithm) based on spread spectrum thought is proposed by Coxetal [1-8] in 1996. At present, watermarking algorithms based on spread spectrum have been applied to images, video, audio, text and other carriers, and the transformation also involves DWT, DCT and DFT.

Quantization index modulation (QIM) is proposed by Chen and Wornell [9] originally. And they have improved the QIM by using Costa's ideas, resulting in distortion-compensated QIM, (DC-QIM) [10]. Recently, the specific QIM methods are dither modulation (DM) and spread transform dither modulation (STDM) [11]. The achievable watermarking algorithm of DC-QIM is distortion-compensated dither modulation (DC-DM) [12]. Other watermarking algorithms using quantization are references [13-17]: quantize carrier data for embedding watermarking information; modify the carrier data according to quantized value and the watermarking to be embedded in order to achieve the embedding of watermarking information.

In this paper, spread spectrum watermarking algorithms and quantization index modulation watermarking algorithm are used for anaglyphic 3D images.

2. DIGITAI WATERMARKING SCHEME FOR ANAGLYPHIC 3D IMAGES BASED ON SPREAD SPECTRUM

The human eyes get stereoscopic sense for the nuances of the objects seen by the left and right eye. To have three-dimensional sense from a planar image, the image must contain the information of two images with a certain parallax. The two images with optic difference will be sent to our left and right eyes by appropriate means respectively.

Any pixel in the color image can be expressed and recorded using a set of RGB values. Generally, color images require information of at least three dimensions. The color image needs to be changed to a grayscale image when embedding watermarking image. After finishing embedding the watermarking image, the grayscale image should restore the original color image. Therefore, the paper has taken the following two decomposition methods:

(1)The RGB is converted to YIQ, and the Y component is the equivalent of grayscale data. Only the value of gray-scale image is an integer from 0 to 255, but Y is the real number of 0 to 1. At the same time, YIQ can restore the original RGB image.

(2) The RGB is converted to RGg, the gray-scale component g replaces the blue component B, and the red component R and the green component G keep unchanged. Because the gray level is derived by $g = p*R + q*G + t*B$, where p=0.2989，q=0.5870，t=0.1140, then $B = (g - p*R - q*G)/t$.

Shannon summarized channel capacity formula from the information theory; the formula can be written by:

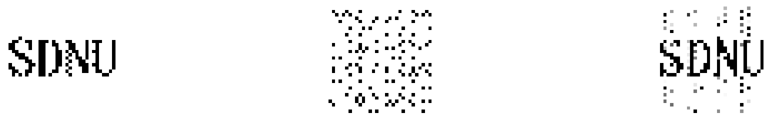
$$C = W\log_2(1+\frac{\delta_X^2}{\delta_n^2}) \tag{1}$$

Where C represents the channel capacity; W is the channel bandwidth; δ_X^2 denotes signal power and δ_n^2 means noise power. The formula shows the relationship between the ability of error-free transmission of information with channel SNR. The procedures of this watermarking algorithm for anaglyphic 3D images are as follows: watermarking is embedded in the maximal N frequency coefficients in the DCT domain; then modify the frequency coefficients to achieve the embedding of watermarking information, and we use the addition criterion [1-2]in this paper. The nature of watermarking algorithm based on SS determines that the original host image is needful for extracting the watermarking if the original meaningful watermarking information is embedded directly without pseudo-random sequence modulation. In order to achieve the blind extraction, the watermarking is modulated with pseudo-random sequence before embedding the watermarking image. After pseudo-random modulation, watermarking image is embedded into the DCT coefficients of 3D image synthesized by two images with certain optic differences.

Figure 1 shows the watermarked image by use of the decomposition method (1) above; the original watermarking and extracted watermarking image are shown in Figure 2. RGB1 and RGB2 are the two images with optic difference. The NC values of extracting watermarking resisting various attacks is listed in Table 1, the watermarked image with PSNR = 41.8847. Where the mean and variance of Gaussian noise is zero and 0.001 respectively; density of salt and pepper noise is taken as 0.001; quality factor of JPEG is 80%.

(a)RGB1 (b)RGB2 (c)Anaglyphic 3D image (d)Watermarked 3D image

FIGURE1: Watermarked Image of The Scheme using SS Technology.



(a)Original watermarking Image (b)Arnold scrambling watermarking (c)Extracted watermarking

FIGURE 2: Extracted Watermarking Images of The Scheme using SS Technique.

Attacks type	No attack	Gaussian noise	Salt & pepper noise	Shrink twice	JPEG compression	Median filtering	Luminance change	Valumetric scaling
NC	1	0.9113	0.9679	0.9950	0.9921	0.9798	0.9967	0.8429

TABLE 1: The NC Values For Extracted Watermarking After Attacks, PSNR=41.8847 dB.

3. WATERMARKING SCHEME FOR ANAGLYPHIC 3D IMAGES BASED ON ADAPTIVE DM WITH THE IMPROVED WATSON PERCEPTION MODEL

Quantization index modulation [9] means modulating one or a series of indexes by use of watermarking to be embedded, and then to quantify the carrier signal by means of corresponding quantizer or quantizer sequence. Quantization can be expressed by

$$y = \Delta * round(\frac{x}{\Delta}) \tag{2}$$

Where Δ denotes that the quantization step, $round(.)$ indicates rounding operation. For the binary watermarking, binary 0 and 1 correspond to two indexes, and the two indexes respond to two quantizers. The function of embedding watermarking can be expressed by

$$\vec{S}(\vec{x};\vec{m}) = q(\vec{X};\vec{m},\Delta) \tag{3}$$

Where Δ means the quantization step size; $q(\vec{X};\vec{m},\Delta)$ denotes the m-th quantizer function with the quantization step size Δ. In the processing of extracting the watermark, minimum distance decoding or maximum likelihood decoding [18] can be adopted.

3.1 Dither Modulation (DM)

DM is a special method of QIM. In order to embed information, dither value may be modulated by the watermarking having been embedded. All available watermarking information to be embedded will map to different dither values. Carrier signal after dither generate the synthesized signal by quantifying. In the case of the basic quantizer $q(\cdot)$, embedding function can be expressed by

$$S(k) = q(X(k) + d[k,b_k]) - d[k,b_k] \tag{4}$$

Here, $d[k,b_k]$ presents the k-th dither when the embedding watermarking bit is b_k; $q(\cdot)$ denotes the quantizer; $X(k)$ indicates the original signal; $S(k)$ means the signal after quantization index modulation. Suppose the embedding watermarking information is a binary sequence, the dither value $d(k,0)$ is a pseudorandom signal usually chosen with a uniform distribution between $[-\frac{\Delta}{2},\frac{\Delta}{2}]$, but the dither $d(k,1)$ should be selected according to the following formula:

$$\begin{cases} d[k,1]=d[k,0]+\frac{\Delta_k}{2}, d[k,0]<0 \\ d[k,1]=d[k,0]-\frac{\Delta_k}{2}, d[k,0]>0 \end{cases} \quad k=1,2,\ldots L \tag{5}$$

3.2 Watson Perceptual Model

Watson perception model, a visual fidelity model put forward by Watson in 1993 [14], based on the block discrete cosine transformation can estimate the perceptibility of images' change.

For Watson perception model, the original image is transformed by $8*8$ blocks, and the luminance masking threshold is shown as formula (6). Where, αT is a constant, usually the value is 0.649; $C_{0,0}$ indicates the mean value of DC coefficients of the original image; $C_0[0,0,k]$ means the DC coefficient of the k-th block; $t[i,j]$ is the sensitivity table defined by Watson perception model that reflecting sensitive degree of the human eyes to different frequency.

$$t_L[i,j,k]=t[i,j](\frac{C_0[0,0,k]}{C_{0,0}})^{\alpha T} \tag{6}$$

The expression of contrast masking threshold is shown in formula (7). The threshold estimates the slacks which mean the change range of each DCT block within the limits of JND.

$$s[i,j,k]=\max(t_L[i,j,k],\left|C_0[i,j,k]\right|^{0.7} t_L[i,j,k]^{0.3}) \tag{7}$$

3.3 Watermarking scheme for anaglyphic 3D images based on adaptive DM with the improved Watson perception model

In order to solve the problem that the slack do not change linearly as the amplitude scale, we modify luminance masking according to formula (8), and the improved slack shown as formula (9). When the image is scale β times, the luminance masking threshold and slack are respectively shown as formula (10) and (11). The operation result shows that the improved slack change linearly with the amplitude scale. Then the adaptive quantization step size can be set based on the improved slack.

$$t'_L[i,j,k]=t_L[i,j,k](\frac{C_{0,0}}{128})=t[i,j](\frac{C_0[0,0,k]}{C_{0,0}})^{\alpha T}(\frac{C_{0,0}}{128}) \tag{8}$$

$$s'[i,j,k]=\max(t'_L[i,j,k],\left|C_0[i,j,k]\right|^{0.7} t'_L[i,j,k]^{0.3}) \tag{9}$$

According to the modified luminance masking threshold $t'_L[i,j,k]$ and slack $s'[i,j,k]$, when the image is resized β times, the luminance masking threshold $\overline{t'_L}[i,j,k]$ and slack $\overline{s'}[i,j,k]$ are resized β times, too.

$$\begin{aligned} &\overline{t'_L}[i,j,k] \\ &= t_L[i,j,k](\frac{\beta C_{0,0}}{128}) \\ &= t[i,j](\frac{\beta C[0,0,k]}{\beta C_{0,0}})^{\alpha T}(\frac{\beta C_{0,0}}{128}) \\ &= \beta t'_L[i,j,k] \end{aligned} \tag{10}$$

$$
\begin{aligned}
&\overline{s'}[i,j,k] \\
&= \max(\overline{t'_L}[i,j,k], \left|(\beta C_0[i,j,k])\right|^{0.7} \overline{t'_L}[i,j,k]^{0.3}) \\
&= \max(\beta t'_L[i,j,k], \beta^{0.7}\left|C_0[i,j,k]\right|^{0.7} \beta^{0.3} t'_L[i,j,k]^{0.3}) \\
&= \beta \max(t'_L[i,j,k], C_0[i,j,k]^{0.7} t'_L[i,j,k]^{0.3}) \\
&= \beta s'[i,j,k]
\end{aligned} \tag{11}
$$

We employ the method of improved adaptive dither modulation and the decomposition method (2) mentioned above to embed the watermarking into the middle frequency coefficients in the DCT domain. The minimum distance detection is used to extract the watermarking. RGB1 and RGB2 are the two images with visual difference; Figure 3 shows the anaglyphic 3D image and watermarked anaglyphic 3D image; the original watermarking image and the extracted watermarking image are shown in Figure 4. PSNR and BER are as a function of image fidelity and accuracy of the extracted watermarking respectively. Table 2 shows the values of BER of extracted watermarking resistance to a variety of attacks when PSNR = 41.7612 dB. Where mean and standard deviation of Gaussian noise are zero and 0.01 respectively; density of salt and pepper noise is 0.001; quality factor of JPEG compression is 80%.

(a)RGB1 (b)RGB2 (c)Anaglyphic 3D image (d)Watermarked 3D image

FIGURE 3: Watermarked Image of The Scheme using Adaptive DM.

(a)Original watermarking image (b)Extracted watermarking image

FIGURE 4: Extracted Watermarking Images of The Scheme using Adaptive DM.

Attacks type	No attack	Gaussian noise	Salt & pepper noise	JPEG	Shrink twice	Low-pass filtering	Cutting	Luminance change	Valumetric scaling
BER	0	0	0.0293	0	0.0195	0.0684	0.0205	0	0.0117

TABLE 2: The BER values for extracted watermarking against attacks, PSNR=41.7612 dB.

It can be seen from the figures and tables illustrated above have good performance in image fidelity and robustness against common signal processing or attacks. Therefore, the two schemes meet the requirements of digital watermarking scheme, which are practicable.

4. SIMULATION AND CONTRAST EXPERIMENTS

In order to denote the robustness of the watermarking schemes, we compare with robust performance of three schemes under the same attacks. Here, SS-3D is the watermarking scheme for anaglyphic 3D images based on the spread spectrum technique; DM-mW-3D means the watermarking scheme for anaglyphic 3D images based on adaptive DM with improved Watson perception model; DM-W-3D indicates the watermarking scheme for anaglyphic 3D images based DM with unimproved Watson perception model. In fairness, both of them employ decomposition method (1) above; adjust PSNR values of the watermarked images to 41.8 dB. Calculate the NC values of extracted watermark to measure the robustness performance.

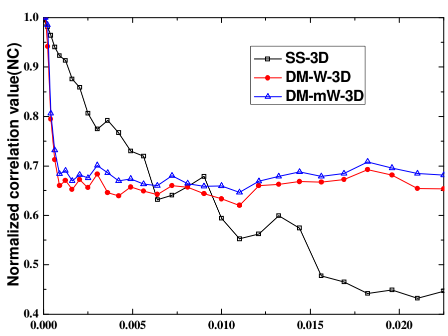
Under the mean of 0 of additive Gaussian noise. The graph of NC values in the two schemes with Gaussian noise is demonstrated in Figure 5 (a) With the increase of standard deviation of additive Gaussian noise, NC values in scheme SS-3D degrade sharply while the change of NC values of scheme DM-mW-3D is stable slightly. Figure 5 (a) shows that the watermarking scheme SS-3D is more sensitive to the Gaussian noise than scheme DM-mW-3D. Scheme DM-mW-3D is more robust against Gaussian noise than scheme SS-3D. In addition, it is clear that resistance to noise of the scheme DM-mW-3D is better than scheme DM-W-3D.

Figure 5 (b) shows the sensitivity of the two schemes to JPEG compression attack for a fixed PSNR of 41.8 dB. That is, we maintain fixed image fidelity. In this case, the sensitivity of watermarking schemes is tested. The performance of watermarking scheme DM-mW-3D is worse than the scheme SS-3D, but better than the scheme DM-W-3D. This shows that our improved scheme is necessary. Scheme SS-3D, for quality factors of less than 63%. Scheme SS-3D, the value of NC is greater than 0.95. There is still a good performance. However, NC values of the extracted watermarking in scheme DM-mW-3D descend sharply when the quality factors are less than 63%. The scheme SS-3D is not sensitive to JPEG compression noise. Because JPEG compression mainly affects the high frequency coefficients so the scheme SS-3D has larger embedded capacity in the medium-high frequency coefficients. Figure 5 (b) shows that the scheme DM-mW-3D for embedded capacity in the low frequency is larger than in high frequency.

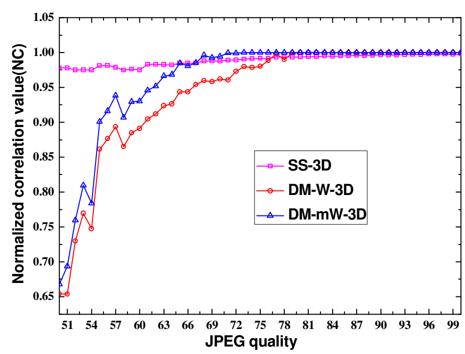
Figure 5(c) illustrates the sensitivity of the schemes to the addition/subtraction of a constant luminance value. Of course, the PSNR is fixed at 41.8 and NC is as a function of extracted watermarking. Watermarking scheme DM-mW-3D and DM-W-3D are significantly superior to scheme SS-3D, which is demonstrated in Figure 5 (c). Scheme SS-3D has a good performance only for variations of luminance change from -45 to 30, while scheme DM-mW-3D is not sensitive to constant luminance change. Compare the scheme SS-3D with DM-mW-3D, the scheme SS-3D attacking robustness of constant luminance changes less stable. This may be caused by the smaller quantization step length.（quantization step is 14）

The curve of NCs of valumetric scaling are shown in Figure 5 (d). It can be found that the scheme DM-mW-3D is better than the scheme DM-W-3D. NC values of extracted watermarking of scheme DM-mW-3D are greater than the NC values of scheme SS-3D. What's more, scheme DM-mW-3D has a good robustness reflecting in the valumetric scaling factors from 0.8 to 1.8. While scheme SS-3D is extremely sensitive to valumetric scaling, and the change of NC values for extracted the watermark is sharp.

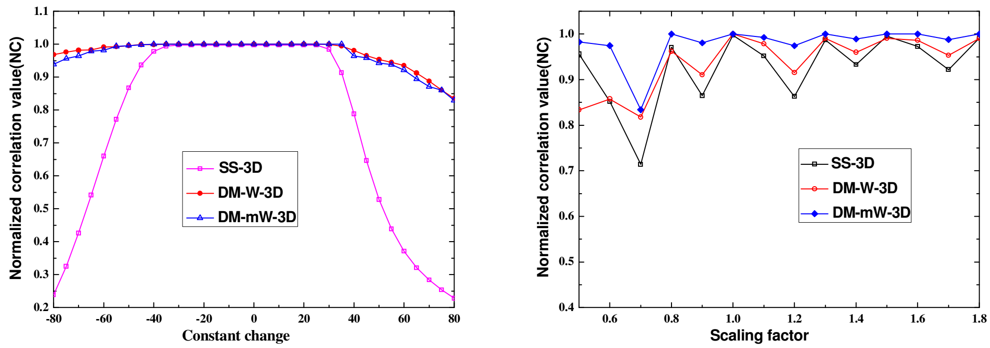
In short, overall performance of our watermarking scheme for anaglyphic 3D images based on adaptive DM with improved Watson perception model is superior to the watermarking scheme for anaglyphic 3D images based DM with unimproved Watson perception model. The data analysis about that are performed in the following paragraph.



(a) The curve of NCs of additive white Gaussian for fixed PSNR of 41.8 dB.



(b) The curve of NCs of JPEG quali noise for fixed PSNR of 41.8 dB



(c) The curve of NCs of constant luminance change for fixed PSNR of 41.8 dB.

(d) The curve of NCs of volumetric scaling for fixed PSNR of 41.8 dB.

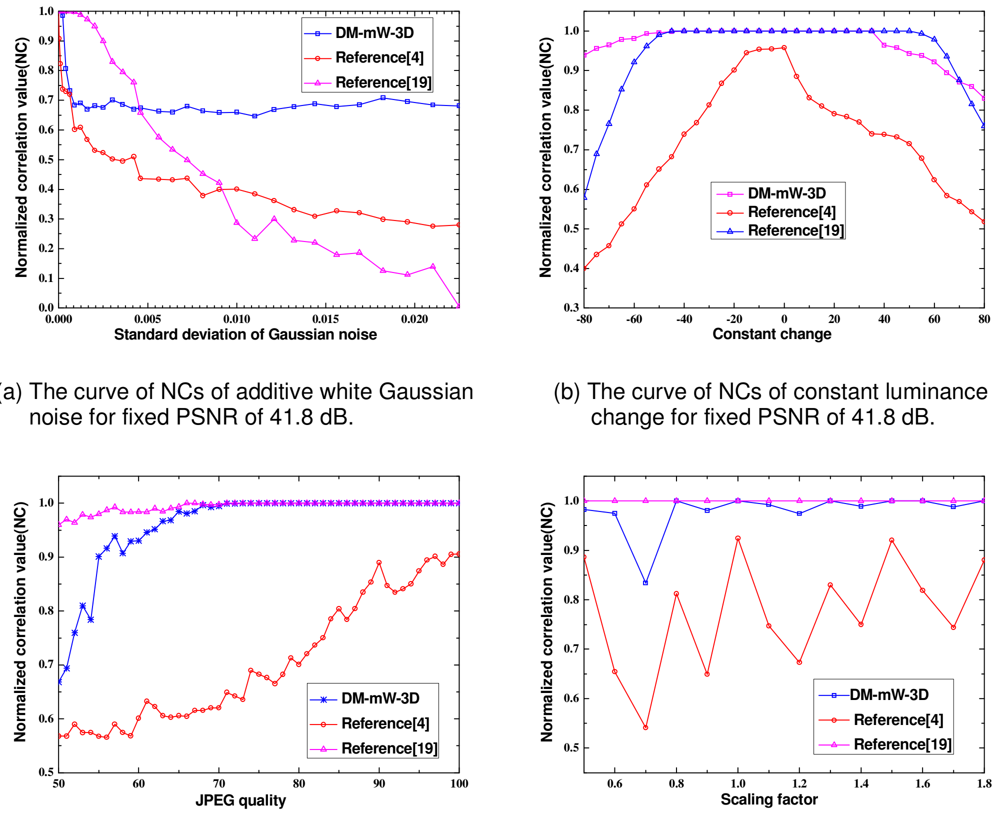
FIGURE 5: Robust Tests of Attacks.

In addition, the contrast experiment between the scheme DM-mW-3D of our paper and the reference [4] and [19] was made; the watermarking scheme of reference [19] is used for video, but the video is incompressible as image sequences, so the comparison experiment is feasible. In the experiments, simulation tests on Gaussian noise, constant luminance change, JPEG compression and valumetric scaling are carried out respectively when the same watermarking invisibility is guaranteed, namely the values of PSNR are all about 41.8 dB, and the results are shown in Figs. 6(a), 6(b), 6(c) and 6(d).

Figure 6 (a) shows that the resistance against Gaussian noise of the paper's scheme is superior to reference [4] and [19]. Reference [4] is most sensitive to Gaussian interference while reference [19] has strong resistance only under the low intensity of Gaussian interference. With the increase of the attack strength, NC values of extracting the watermarking fall sharply. It can be seen in the Figure 6 (b) that the solution of our paper can extract the watermarking certainly when attack parameters of constant luminance change are between -80 and 80 while reference [4] can hardly extract the watermarking and reference [19] can extract the watermarking only the parameters about the attack between -65and 65. There is no doubt that the effect of scheme DM-mW-3D is better than reference [19] .

Figure 6 (c) shows the results of JPEG compression attack, and the methods of our scheme and reference [19] perform better than reference [4]. It is regret that the performance of our scheme is not better than the one of reference [19] when strength of JPEG compression is larger.

The curve of NCs of valumetric scaling are shown in Figure 6 (d). We found that the NC values of literature [4] fluctuate up and down with the increase of attack strength; that may be due to the image is saved as uint8 format and uint8 data format conversion is similar to the noise attack. In addition, NC values of reference [19] are all 1 when the scaling factors are between 0.5 and 1.8, so we increased the attack strength. It can also extract the watermarking when the scaling factor is about 0.3, and NC value is 0.3256 when the scaling factor is 0.2, namely the watermarking have not been extracted. The resistance against JPEG compression attack of the paper is not stronger than reference [19], but also it has good performance for the compression factor exceed to 63, that means the scheme is effective within restricted attack strength.



(a) The curve of NCs of additive white Gaussian noise for fixed PSNR of 41.8 dB.

(b) The curve of NCs of constant luminance change for fixed PSNR of 41.8 dB.

(c) The curve of NCs of JPEG quality for fixed PSNR of 41.8 dB.

(d) The curve of NCs of valumetric scaling for fixed PSNR of 41.8 dB

FIGURE 6: Comparison Experiment Results.

5. CONCLUSIONS

In this paper, we proposed two digital watermarking schemes for anaglyphic 3D images. The first one is watermarking scheme for anaglyphic 3D images based on SS. The results show that the watermarked anaglyphic 3D images have high fidelity, and the PSNR is up to 41.8847dB. Under the premise of such high fidelity, this scheme has good robustness which could be against common signal processing or attack. This scheme has certain contribution to the copyright protection of stereo image.

Secondly, another watermarking scheme for anaglyphic 3D images is based on adaptive DM with improved watson perception model. The modified gap can be used to calculate the adaptive quantization step size, and we apply this scheme to the watermarking technology for 3D images. The experimental results demonstrate that watermarked 3D images still have satisfactory fidelity and good robustness as well. BER values of extracted watermarking resistance to Gaussian noise, salt and pepper noise, JPEG compression, constant luminance change and valumetric scaling are less than 0.07.

Finally, We fixed the same image fidelity and used the same color basis decomposition method. The sensitivity of the three watermarking schemes is tested for Gaussian noise, JPEG compression, constant luminance adjustment, and valumetric scaling. The experimental results demonstrate that there is an improvement in the performance of the watermarking scheme for anaglyphic 3D images based on adaptive DM with improved Watson perception model. In this paper, the performance of the first watermarking scheme is stable to resist the JPEG compression attack. But the performance of the Gaussian noise and valumetric scaling is poor. This scheme is not sensitive to the intensity of the attack when the constant luminance change of the attack is relatively small. The performance of the second watermark scheme changed slowly and stably when we adjusted the constant luminance change and changed the attack intensity of valumetric scaling. There is an overall stability of the performance when subjected to Gaussian noise and JPEG compression.

The contrast experiment between the scheme DM-mW-3D of our paper and the reference [4] and [19] was made; the DM-mW-3D scheme can achieve satisfactory effect for Gaussian noise, constant luminance change and valumetric scaling attacks and the sensitivity for Gaussian of the paper is significantly lower than another two references. We have a plan of combining the two watermarking schemes. For example, the method in [20] is successful and typical. This is the future work we will carry out to improve the research.

6. ACKNOWLEDGEMENTS

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