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NON LINEAR HYBRID WATERMARKING FOR HIGH DYNAMIC RANGE IMAGES

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NON LINEAR HYBRID WATERMARKING FOR HIGH DYNAMIC RANGE IMAGES

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ABSTRACT

The present work explores the use of a specific method, called non linear hybrid watermarking to watermark High Dynamic Range (HDR) images. The non linear hybrid technique combines both additive and multiplicative watermark embedding and is based on a square root embedding equation. We evaluate the robustness and objective quality of HDR tone mapped watermarked images on two different HDR databases. The experimentations show that the watermark is imperceptible and successfully survives tone mapping attack.

***Index Terms*—** HDR image, hybrid watermarking, tone mapping, wavelet domain.

1. INTRODUCTION

The High Dynamic Range (HDR) images are becoming more and more popular. HDR images present a better accuracy at rendering the range of intensity levels in natural images. In HDR images, basically the pixels are encoded using floating point values, instead of the classical one byte (256 levels) per chromatic component in Standard Definition Resolution (SDR) images. Among the various HDR image formats, the most commonly used is the RGBE format. There is an important interest on tone mapping operators, which aim at displaying HDR radiances onto standard displays [1, 2]. Tone mapping algorithms scale the dynamic range down while attempting to preserve the appearance of the original image captured.

The need for an appropriate watermarking technique specifically adapted or designed for HDR images is an important issue. The watermark must survives various tone mapping processings. Although digital watermarking have been studied on almost every sort of digital media, very few watermarking techniques have been designed specifically for HDR images so far [3, 4, 5]. In [3, 4], the authors proposed to embed the watermark in the luminance domain. First, the original HDR image is transformed to a reference image by applying RGB-to-LogL transformation. Then, the watermark is embedded in the approximation (LL) sub-band by using a QIM [1] approach. The LL sub-band is partitionned onto several blocks and each block is watermarked by using a perceptual mask. Finally, the reverse log transform is applied. In [5], the authors presented an HDR watermarking technique based on modification of blue component of HDR image. Small scale and texture parts of the blue component of HDR image, known as detail layer, are extracted through the use of a bilateral filter and afterward watermarked (multiplicative embedding).

The state of the art of HDR watermarking techniques embed the watermark in the high contrast areas of the images/videos. In this present work, a different approach is considered. A recent study [6] showed that embedding away from the image edges (or high contrast areas) can increase the robustness while granting a very good perceived quality. This technique is called hybrid additive/multiplicative watermarking technique [6]. We propose to adapt a special case of hybrid watermarking called non linear hybrid watermarking to HDR images. The watermark is embedded in the R, G and B radiances of the original HDR image. The robustness performances of our method have been assessed against six tone mapping operators. Finally, the objective quality have been studied.

This paper is structured as follows: In section 2, we present the system framework and describe the non linear hybrid embedding technique. Section 3 shows some experimental results for various HDR images both in terms of detection performances and image quality. Finally, section 4 will conclude our works and discuss future research directions on HDR image watermarking.

2. HDR NON LINEAR HYBRID WATERMARKING TECHNIQUE

2.1. Watermarking system

The block diagram of the proposed HDR non linear hybrid watermark embedder scheme is shown in Fig. 1. The R, G and B radiances of the original HDR image are involved in the watermarking process. The E component is left untouched in order to avoid severe distortions. First, a normalization preprocess is performed on the original image in order to apply the same watermark strength independently of the acquisition parameters (dynamic range of pixel values). The nor-

[1] Quantization Index Modulation

malized HDR image have its pixel values in the range $[0, 1]$. Then, each radiance is decomposed by the wavelet transform (DWT: CDF 9/7 bi-orthogonal wavelets) for a one level resolution into a collection of sub-bands. Afterwards, non linear hybrid watermarking algorithm is applied onto the horizontal detail sub-bands (LH_R, LH_G,LH_B). The same noise like watermark is spread onto one detail sub-band at a time. Finally, the inverse wavelet transform is applied obtaining watermarked radiances and thus getting the watermarked version of the given original HDR image.

The watermark detection is achieved by following the steps below : the R, G and B radiances of the potentially watermarked HDR image are decomposed by the DWT and the LH sub-bands are transmitted to the detection block. During the detection process, the normalized cross-correlation is computed for every sub-band and the maximum value is returned by the detector.

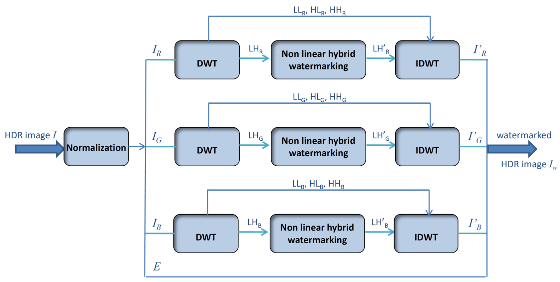


Fig. 1. The block diagram of the of the HDR non linear hybrid watermark embedder scheme.

2.2. Embedding method

Non linear hybrid watermarking [6] uses the following embedding equation :

$$y_{i,j} = x_{i,j} + (\alpha \times \sqrt{x_{i,j}} + \beta) \times w_{i,j}, \tag{1}$$

where $y_{i,j}$ is a watermarked wavelet coefficient at position (i, j), $x_{i,j}$ is the corresponding original wavelet coefficient, α and β are strength parameters, and $w_{i,j}$ is a noise like 2-D watermark following a Gaussian distribution.

The use of $\sqrt{x_{i,j}}$ instead of x (in the wavelet domain) induces a non-linear embedding: the lowest wavelet coefficients (low contrast areas) will be more strongly watermarked while the highest wavelet coefficients (high contrast areas/edges) will benefit from a reduced embedding strength. Interested reader may refer to [6] for further details on the optimal (subjective) embedding strengths. Such an embedding scenario is particularly interesting for High Dynamic Range images where the floating point radiances composing the image give a much more accurate representation of the contrast.

2.3. Detection method

The detection method is blind. It computes the correlation between the possibly marked wavelet sub-band and the noise-like 2-D watermark (which was stored beforehand). A 2-D normalized cross-correlation was used between y and w as in [7]:

$$y \bigstar w = \mathcal{F}(\bar{Y(\nu)} W(\nu)), \tag{2}$$

where $\mathcal{F}$ is the inverse Fourier Transform, $\bar{Y(\nu)}$ is the complex conjugate of the Fourier Transform of y, and $W(\nu)$ is the Fourier transform of w.

3. EXPERIMENTAL ANALYSIS

The HDR image database used in our test is an heterogeneous set of 32-bit RGBE encoded images collected from two sources: the Munsell Color Science Laboratory's [2] (Five images: *Splitcube*, *Colorcube*, *Atrium*, *Chair* and *Hallway* of size 2000×1312) and Greg Wards website repositories [3] (Seven images: *Tree* of size 928×906, *Memorial* of size 512×768, *Rend01* of size 1024×1024, *Apartment* of size 2048×1536, *AtriumNight* of size 760×1016, *Desk* of size 644×874 and *Fog* of size 751×1130). The selection was performed so as to provide some variety in terms of subjects being represented as well as image sizes and dynamic ranges. The embedding strengths are set as follows: $\alpha = 0.002$ and $\beta = 0.0001$.

We point out that we are not able to compare our results with those of the state of art [3, 4, 5]. The main reason is that the watermark technique used by each author is completely different from ours. In [3, 4], the detection performance is given in terms of missed blocks (the detection process is applied to each extracted block) and not in terms of correlation values. In [5], the watermark is extracted and not detected and the authors did not consider the tone mapping attack in their experimentations.

3.1. Robustness against tone mapping

We study the robustness of the proposed watermarking technique against tone mapping (TM). Six TM operators were tested [1, 8, 9, 10, 2, 11] : four [4] are part of the *pfstools* package [5] ([10]), the fifth one is the Kuang *et al* ICAM TM operator [2] and the last one is the Ward *et al* TM operator [6] [11]. Once watermarked, each HDR image goes through the

[2] Available for download at: `http://www.cis.rit.edu/mcsl/icam/hdr/rit_hdr`

[3] Available for download at: `http://www.anyhere.com/gward/hdrenc/pages/originals.html`

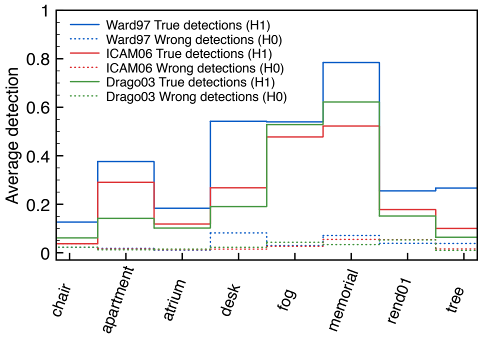
[4] Mantiuk *et al* (2008), Reinhard *et al* (2005), Drago *et al* (2003) and Fattal *et al* (2002) TM operators.

[5] pfstools is Available at: `http://pfstools.sourceforge.net/`

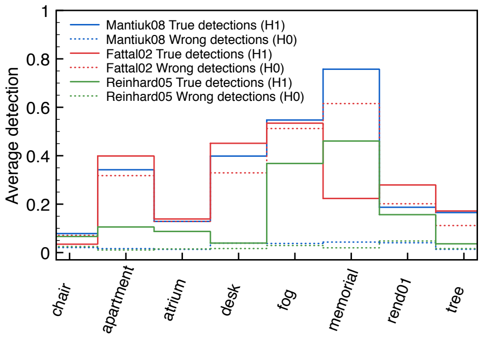
[6] Matlab TM operator.

tone mapping attacks. The watermark detection is afterward performed on the tone mapped image.

Fig. 2 presents the average detection performances against tone mapping for the two classical hypothesis: H0, the detector seeks for a watermark which is actually not embedded into the host media and H1 where the detector seeks for the correct watermark. Eight images are considered. For each image, 100 different watermarks are embedded for each hypothesis and the average detection is computed. Solid lines stand for true detections (H1) while dotted lines correspond to false detections (H0). The bigger is the distance between



(a)

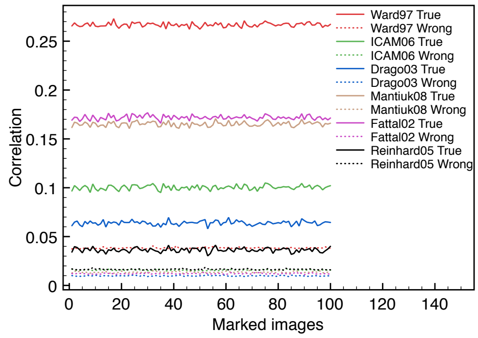


(b)

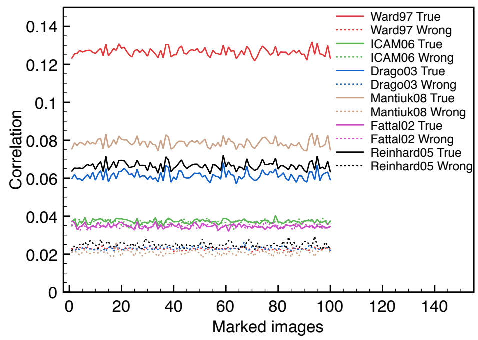
Fig. 2. Average Detection performances for 8 images against: (a) Ward [11], ICAM [2] and Drago [9] TM operators, (b) Mantiuk [1], Fattal [10] and Reinhard [8] TM operators.

the solid and the dotted lines, the better is the detection. Although the robustness performances strongly differ between the tone mapping operators, we can observe that the watermarking technique successfully survives all the tested TM operators. Among the 8 tested images, the *Chair* and *Tree* images exhibited the lowest detection performances. Thus, in the following, we focus in more details on these two images.

The detection performances for the *Tree* and *Chair* images are illustrated in Fig. 3. We note that for the *Tree* image (Fig. 3.a), the detection is done correctly for the six TM operators. It is not the case for the *Chair* image (Fig. 3.b) as the detection fails against Fattal [10] and ICAM [2] TM operators.



(a)



(b)

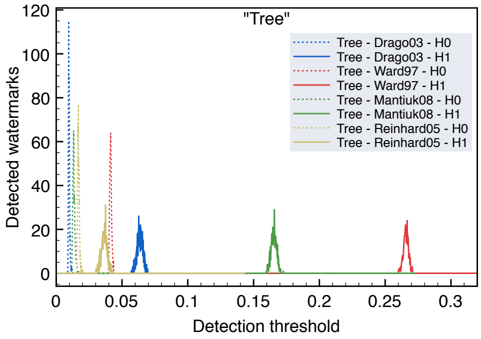
Fig. 3. Detection performances for: (a) *Tree* image, (b) *Chair* image, against six TM operators.

We also study the distribution of the detection for H0 and H1. For each HDR image, 1000 different watermarks were embedded. We show on Fig. 4 the distribution of the detection for the *Tree* and *Chair* image against four TM operators. Considering the *Tree* image (Fig. 4.a), we can notice that for Ward [11] and Mantiuk [1] TM operators, the detection threshold corresponding to H1 is far away from that corresponding to H0. It means that the detection is efficient. The gap is smaller for Reinhard [8] and Drago [9] TM operators. For the *Chair* image (Fig. 4.b), we note that the distributions are closer from each other.

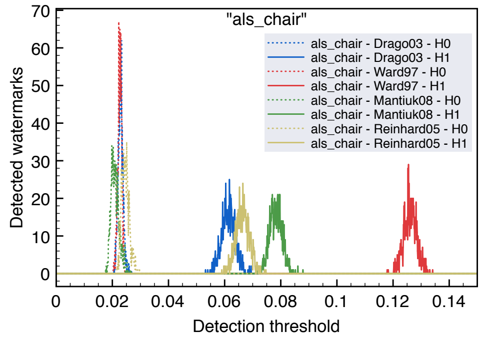
3.2. Quality assessment

Quality is evaluated through the HDR-Visual Difference Predictor (HDR-VDP) tool [7] [12], which is a full-reference visual difference metric. Given two similar images, the output of the HDR-VDP is the percentage of pixels that, according to its model, a human observer would perceive as different. Table 1 gives the HDR-VDP values for four images. The results are very good for *Chair*, *Tree*, *Apartment* and *Rend01*.

[7]The source code is available at : `www.sourceforge.net/apps/mediawiki/hdrvdp/index.php`



(a)



(b)

Fig. 4. Detection distributions against 1000 watermarks : (a) *Tree* image, (b) *Chair* image, attacked by four TM operators (Drago [9], Ward [11], Mantiuk [1] and Reinhard [8]).

The percentage is below 90% for the *Memorial* image. An exemple of a watermarked and tone mapped image is shown on Fig. 5. We notice that from a perceptual point of view, the distortions induced by the watermark are imperceptible. The watermarked HDR radiances do not present any visible distortions when displayed on a HDR display [8].

Image	HDR-VDP (%)
Chair	94.042
Apartment	98.032
Memorial	84.137
Tree	94.288
Rend01	94.739

Table 1. HDR-VDP values for watermarked HDR images.

[8]Assessed by 3 observers on a SIM 2 full HDR display of size 1020 × 1080

Fig. 5. Watermarked image *Chair* after tone mapping (Mantiuk [1] TM operator).

4. CONCLUSION

We have presented in this paper an adaptation of the non linear hybrid watermarking for High Dynamic Range image. Contrary to previous works on HDR image watermarking [4, 5], we embed the watermark both into the high activity areas and smoother areas but with a lower strength along the high contrast edges of the images. We have evaluated the robustness of the watermark against tone mapping. Our experiments showed that the watermark survives different type of TM processing. The quality performances have also been assessed. Further investigations will involve the use of a subjective experiment to determine the optimal watermark strengths (α and β values) for the considered HDR image database. This experiment will be set under normalized viewing conditions and human observers will be asked to tune inependently α and β parameters until the visibility threshold will be reached.

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