HIGH DYNAMIC RANGE MEDIA WATERMARKING ISSUES AND CHALLANGES

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ABSTRACT

High Dynamic Range (HDR) imaging techniques are capable of capturing the full range of lighting in a real world scene. Unlike traditional imaging, with HDR there are no more under- or over-exposed pixels. HDR imaging techniques are therefore becoming more prevalent due to the greater quantity and quality of information they can convey with respect to traditional Low Dynamic Range (LDR) approaches. Accordingly, there is an increasing need for novel watermarking methods able to cope with the peculiarities of HDR content to prevent the misappropriation of HDR image and videos. This paper presents a review of the state of the art on HDR watermarking and highlights some associated issues and challenges.

***Index Terms*—** High Dynamic Range, image, watermarking.

1. INTRODUCTION

Traditional imaging technology is not able to capture the full range of light and color that our eyes can see in the real world. Digital images captured from scenes with a wide range of lighting have areas of underexposed or over exposed pixels. High Dynamic Range (HDR) imaging techniques are especially designed to acquire the full range of lighting in a real scene. By merging several single exposure Low Dynamic Range (LDR) images, HDR techniques are able to create an image that more closely matches what our eyes can see. Most modern single-lens reflex (SLR) cameras and even mobile phones are capable of capturing HDR images. Human eyes can see in a wide range of light from moonlight to bright sunshine. Within this wide range, as our eyes are constantly moving and adapting, we have a dynamic contrast ratio of nearly 1,000,000:1. This equates to about 20 f-stops, where an f-stop (focal-stop) is a measure of how much light is allowed to enter the lens of a camera. Each consecutive f-stop halves this amount of light.

Figure 1: Capturing and displaying the full range of light in a scene with HDR from “the sun” to the darkest areas.

Figure 2: Tone mapped image of a scene after being captured with (left) 20 f-stops (right) 16 f-stops. Missing detail indicated in red [1].

There are many in the film and television industry that believe that capturing 16 f-stops, the dynamic range of traditional film, is sufficient to capture real-world lighting. While many real world scenes do indeed contain less than 16 f-stops, this is not the case in scenes with extreme lighting, as in Figure 1. Furthermore, as Figure 2 shows, failure to capture all the lighting in the scene can result in significant loss of information which can no longer be recovered [1]. HDR imaging techniques are therefore able to provide images and videos much more valuable, in terms of the quantity and quality of information they can carry, with respect to traditional approach.

This paper reviews previous works which have been done to address one of the many challenges which need to be tackled for the widespread adoption of HDR techniques: namely watermarking. Within this framework watermarking is employed to enforce the protection of the intellectual property, namely copyright, of HDR content with emphasis on HDR images. This is especially challenging as existing

LDR watermarking approaches are not adequate to cope with the large range of lighting contained in an HDR image.

The paper is organized as follows. In Section 2 a brief historical overview on digital watermarking is given as long as with the main requirements of digital watermarking techniques. In Section 3 a review of the state of the art of digital watermarking techniques specifically designed for HDR images are given. Eventually, in Section 4 some issues and challenges related to the design of efficient and effective HDR images watermarking techniques are highlighted.

2. DIGITAL WATERMARKING

In the past few years, there has been an explosion in the use and distribution of digital multimedia data, essentially driven by the diffusion of the Internet. In this scenario, digital watermarking techniques [2], [3] have been designed to answer the ever-growing need to protect the intellectual property (copyright) of digital still images, 2D and 3D video sequences, or audio from piracy attacks in a networked environment like the World Wide Web. Although copyright protection was the very first application of watermarking, different uses have been proposed in literature. Fingerprinting, copy control, broadcast monitoring, data authentication, multimedia indexing, content-based retrieval applications, medical imaging applications, error concealment, quality assessment, and improved data compression are only a few of the applications where watermarking can be usefully employed.

Roughly speaking, digital watermarking is the general process by which a discrete information stream is merged within media content. The general watermark embedding procedure consists of inserting a watermark sequence, which is usually binary, into a host data by means of a key. In the detection/extraction phase, the key is used to verify either the presence of the embedded sequence or to extract the embedded mark. When considering a watermarking scheme, depending on its specific application, different requirements need to be achieved. One of them is the *imperceptibility* of the superimposed mark onto the host data. This implies that the alterations caused by the watermark embedding into the host should not degrade its perceptual quality. Moreover, when these techniques are used to preserve the copyright ownership with the purpose of avoiding unauthorized data duplications, the embedded watermark should be detectable. This is required even if malicious attacks or non-deliberate modifications (i.e., filtering, compression, etc.) affect the embedded watermark. This requirement is known as watermark *security*. When the watermark is required to be resistant only to non-malicious manipulations the watermarking techniques is referred to as *robust*. For some applications, when the robustness requirement is severely required, each attempt of removing the mark should result in irreversible data quality degradation. As a consequence the quality of the image must noticeably decrease before the removal attempt succeeds. However in some applications the host data are intended to undergo a limited number of signal processing operations. Therefore we talk about *semi-fragile* watermarking when the watermark needs to be robust only to a limited number of set of manipulations, while leaving the perceived quality of the host data intact. On the contrary, when unwanted modifications of the watermarked data affect even the extracted watermark, the embedding scheme is known as *fragile*. Fragile watermarking can be used to obtain information about the tampering process. In fact, it indicates whether or not the data has been altered and supplies localization information as to where the data was altered. *Capacity* is another watermarking requirement, referring to the number of bits of information that can be embedded in the original data, which needs to be fulfilled, depending on the specific application. Each requirement typically conflicts the others. Therefore the optimal trade-off is strictly tied to the target application.

3. HDR IMAGE DIGITAL WATERMARKING: STATE OF THE ART

Despite HDR imaging is rapidly emerging as an innovative approach for representing real scenes characterized by significant contrast, a very limited research effort has been devoted so far to design both HDR image and video digital watermarking schemes. In fact HDR media possess some peculiarities with respect to LDR ones which do not allow a straightforward transposition of the plethora of watermarking approaches already developed for LDR images and videos to the HDR case. When designing watermarking approaches tailored to HDR media, both the imperceptibility and the robustness requirements need to be properly tuned to the very nature of the HDR media. As an example specific characteristics of the human visual system (HVS) need to be taken into account in order to take advantage of its masking properties when dealing with HDR media. Moreover HDR oriented watermarking schemes need to be robust against intentional attacks or against signal processing manipulations like compression or tone mapping operators (TMO). These latters have to be applied to the considered HDR media when using conventional displays in order to generate LDR data retaining as much information as possible from the original objects, while reducing the overall contrast. Therefore it would be highly desirable to design HDR oriented watermarking schemes robust also against TMOs, thus allowing to recover the embedded mark not only from the marked HDR image, but also from its tone-mapped version. In the following, far from being exhaustive, an overview on the state of the art in HDR image watermarking is given. A synthetic summary of the methods reviewed in this paper is given in Table 1.

In [4], binary information is inserted into an HDR image encoded in RGBe format by substituting the Least Significant Bits (LSBs) of each pixel representation with bits taken from the secret message. In more details, the HDR image is divided into flat and boundary areas by comparing the exponents associated to neighboring pixels. The number of bits which can be embedded into each color channel is then adaptively determined on the basis of local contrast and depending on the considered area, trying to embed more bits in high contrast and dark regions than in smooth and bright ones. The capacity of this method, tested over seven HDR images, is around 10 bits per pixel (bpp), while its imperceptibility is evaluated by converting the HDR images into their LDR counterparts by means of a TMO, and measuring the Peak Signal-to-Noise Ratio (PSNR) between the tone-mapped cover-image and the tone-mapped watermarked image, obtaining values around 30dB.

Images in uncompressed LogLuv TIFF format are considered in [5], where the LSB of each channel's mantissa is modified to insert a binary message, while the exponent is selected in order to minimize the difference between the final value and the original one. The visual quality of images processed according to this technique is evaluated over seven HDR images by computing the PSNR and the HDR-Visual Difference Predictor (HDR-VDP) metric [6] on the LDR images obtained by tone-mapping the HDR ones.

The RGBe format is also considered in [7], where its property of expressing a given color according to different possible choices is employed to hide a message into an HDR image, by selecting the actual color representation among the equivalent ones on the basis of the bits of the secret message. Such approach produces distortion-free watermarked images, being any difference with the original cover-image due just to the conversion employed to determine the floating point value of the pixels. No visible difference is therefore present between the cover and the watermarked HDR images or between their LDR counterparts, while a capacity of about 0.12bpp is estimated over five HDR images. It is worth noting that the aforementioned approaches do not take into account any kind of either intentional or unintentional attack.

Two different watermarking methods are investigated in [8]. Both of them consist in splitting the cover HDR image into a host image where to embed the mark and a residual part. They are eventually recombined after the embedding process has taken place. More in details, the first approach the author propose employs the μ-law to characterize a general TMO, and apply it to the original HDR image to derive an LDR representation where the watermark can be embedded, while the residual part is defined as the ratio between the HDR and the LDR image. Any method already proposed for watermarking LDR images can be then employed. It is however worth observing that, since the range of HDR images may be orders of magnitude greater than the one of LDR images, the ratio between them will be high in correspondence of areas with high luminance, where the watermark will be therefore very intense. The second approach is based on splitting the image into a detail and a coarse image. The watermark embedding is performed in the detail part. In fact, it is assumed that the application of a TMO to an HDR image addresses the problem of strong contrast reduction from the scene values to the displayable range, while preserving the image details and the color appearance, which mostly allow appreciating the original scene content. Bilateral filtering is applied to the HDR image to derive a coarse representation of it by smoothing the image while preserving its edges. The ratio between the original HDR image and its filtered version is computed to derive a representation of the image details and its logarithm is then evaluated. As a result shadow areas, to which humans are typically sensitive, are enhanced, while the bright parts of the image are lowered. Both of the proposed methods employ spread-spectrum (SS) approach to insert a watermark into the details of the discrete wavelet transform (DWT) of the luminance. At the receiving side the presence of the watermark is detected by using correlation-based techniques. The reported experimental tests, conducted using five HDR images and four local TMOs, testify that the visual quality of images marked with the μ-law-based approach, evaluated by means of the PSNR computed over tone-mapped images, is better than the one associated with the method relying on bilateral filtering. Specifically, the PSNR of images marked with the first approach is within the 50-70dB range, while the second one produces images with a PSNR of about 30-60dB. However, bilateral filtering allows achieving better performance in terms of robustness to the application of TMOs on the marked HDR images.

In [9] the preprocessing stage proposed in [8], consisting in dividing an HDR image into its LDR counterpart and a residual part, is employed. A set of four different TMOs are taken into account for both embedding the watermark and attacking the marked HDR image to extract the hidden information. Moreover, differently from [8], a multi-bit mark is blindly embedded into an image by associating each bit to a specific 8x8 luminance block and by manipulating two middle-frequency DCT coefficients of the processed block in order to let their relative difference being dependent on the bit to be embedded. Experimentations have been performed on a set of four HDR images obtaining a PSNR for tone-mapped watermarked images of about 40dB, while the method robustness against TMOs is evaluated by estimating the bit-error-rate (BER) between the mark embedded in the HDR image and the one extracted from the tone-mapped watermarked image. More specifically, several attacks are applied to the obtained marked LDR images, like cropping, Gaussian blur and Gaussian noise addition, resulting in BERs of about 12%, 23% and 15%, respectively.

In order to define a watermarking method able to withstand the non-linear distortions of TMOs, a general tone-mapping represented by the logarithm function is considered in [10] and applied to the luminance of the cover HDR image. The watermark is embedded by means of a quantization-index-modulation (QIM) approach into the approximation subband of the DWT of the LogLuv domain

Paper	Embedding Domain	Embedding Method	Database	Performance		
				Capacity	Imperceptibility	Robustness
[4]	Pixels' values in RGBe format (32 bit)	Least Significant Bits (LSBs) substitution	7 images (Ref. not specified)	~ 10bpp	PSNR on LDR images (1 TMO used) ~ 30 dB	Not evaluated (attacks not considered)
[5]	Pixels' values in TIFF LogLuv format (48 bits)	LSBs of each pixel's mantissa	10 images (Ref. not specified)	~ 26bpp	PSNR on LDR images (1 TMO used) ~ 35 dB $HDR\text{-}VDP_{75}$ ~ 0.42% $HDR\text{-}VDP_{95}$ ~ 0.04%	Not evaluated (attacks not considered)
[7]	Pixels' values in RGBe format (32 bit)	Exponents of each pixel	125 images (Ref. not specified)	~ 0.12 bpp	No noticeable variation (pixels' values remain as in the original)	Not evaluated (attacks not considered)
[8]	1^{st} - 3^{rd} -level wavelet detail subbands of the luminance of an LDR image obtained 1.with μ-law as TMO 2.with bilateral filter for removing the large-scale part	Multiplicative modification of the original coefficients	5 images from [13]	1 bit (detection)	1. PSNR on LDR imgs (4 TMOs) ~ 55 dB 2. PSNR on LDR imgs (4 TMOs) ~ 45 dB	Against 4 TMOs: 1.detection scores 2 times bigger than the threshold for $P_{fa}=10^{-8}$ 2.detection scores 7 times bigger than the threshold for $P_{fa}=10^{-8}$
[9]	DCT transform of the luminance of an LDR image obtained using a TMO	Modification of the difference between adjacent middle-frequency DCT coefficients	4 images from [13]	4800 bits embedded	PSNR on LDR images (4 TMOs) between 40dB and 70dB	Best performance against 4 TMOs: BER ~ 5% Against cropping of HDR images: BER ~ 12% Against blurring of HDR images: BER ~ 22% Against Gaussian noise added to HDR images: BER ~ 15%
[10]	2nd-level wavelet approximation subband of the logarithm of luminance	QIM of the kurtosis of image blocks	15 images from [13] and [14]	1 bit (detection)	$HDR\text{-}VDP_{75}$ ~ 0.46% $HDR\text{-}VDP_{95}$ ~ 0.21%	Against 7 TMOs: $\max\{P_{miss}\} = 10^{-2}$ at $P_{fa} = 10^{-6}$ Against random noise added to the HDR image: $\max\{P_{miss}\} = 10^{-12}$ at $P_{fa} = 10^{-6}$
[11]	1^{st},2^{nd},3^{rd} -level wavelet detail subbands of the JND space; use of perceptual masks	Multiplicative modification of the original coefficient	3 HDR images from [15]	128 bits embedded	Maximum detectability with HDR-VDP-2 [12] ~ 1%	Against 7 TMOs: detection EER always < 10^-3, BER ~ 5%

Table 1: Summary of HDR watermarking approaches

thus obtained. Specifically, the image is divided into different blocks of random shapes, and the coefficients of each block are modified in order to make the block kurtosis equal to a quantized value determined by the bit which has to be embedded into the block. A non-uniform quantization is employed to better match the behavior of the exploited kurtosis feature, given that invariance requirements are less strict as its value increases. A sequence of bits can be extracted from the marked image by evaluating the kurtosis of each block and then recovering each bit of the string by taking the binary value associated with the quantized level closer to the computed kurtosis. The extracted mark is eventually compared with the one supposed to have been embedded in the analyzed image in order to detect its presence. A local perceptual mask based on luminance, texture and contrast is employed to achieve mark imperceptibility by providing the maximum amount of distortion that each coefficient in the embedding domain can sustain without resulting in visible artifacts. The reported experimental tests are conducted on fifteen HDR images, and include an objective analysis on mark imperceptibility evaluated by computing the HDR-VDP metric between unmarked and marked HDR images, as well as an investigation on the robustness of the proposed technique with respect to seven different TMOs and with respect to the addition of Gaussian noise in the HDR domain.

In [11] a blind multi-bit watermarking method for HDR images is proposed. The approach is designed in order to guarantee the watermark imperceptibility both in the HDR marked image and in its LDR counterpart, being thus robust against significant non-linear distortions such as those performed by TMOs. In order to do so, the wavelet transform of the Just Noticeable Difference (JND)-scaled space of the original HDR image is employed as embedding domain. Moreover, a visual mask taking into account specific aspects of the Human Visual System (HVS) is exploited to improve the quality of the resulting watermarked image. Specifically, bilateral filtering is used to locate information on the detail part of the HDR image, where the watermark should be preferably embedded. A contrast sensitivity function is also employed to modulate the watermark intensity in each wavelet decomposition subband according to its scale and orientation. An extensive set of experimental tests has been conducted by considering three HDR images with different perceptual characteristics, together with several TMOs employed to generate different LDR versions of the evaluated images, testifying that the proposed scheme can be employed to efficiently embed in HDR images messages which can be blindly extracted with high accuracy from both the marked HDR images and their tone-mapped versions, without affecting the visual quality of the processed data. Imperceptibility is evaluated through the HDR-VDP-2 metrics [12] and robustness against seven TMOs has been tested obtaining an EER always less than 10^{-3} and a BER around 5%.

4. CHALLENGES IN HDR WATERMARKING

In the previous paragraph we have summarized the main approaches which have been designed for HDR image watermarking, and a comparative analysis has been reported in Table 1. Although digital watermarking has flourished in the last couple of decades, HDR watermarking is still in its infancy. In fact, the peculiarities of HDR media do not always allow to directly transposing the well consolidated watermarking strategies for LDR media to the HDR case.

Specifically, a not perceptible HDR watermarking approach needs to rely on the HDR related masking properties of the HVS. This issue has not been extensively investigated in the proposed approaches. Databases of scene-referred images are greatly needed too, especially for properly assessing the imperceptibility requirement through objective evaluations of metrics such as HDR-VDP-2, which requires absolute luminance units in cd/m^2 to properly compute the responses of the HVS to the provided stimuli. Beside imperceptibility, robustness against TMOs is another key issue that needs to be taken into account if HDR content need to be displayed on LDR enabled devices. Moreover, HDR video watermarking is still totally unexplored.

5. ACKNOWLEDGEMENTS

The authors acknowledge the EU COST Action IC1005 “HDRi: The digital capture, storage, transmission and display of real-world lighting”. P. Campisi and E. Maiorana activity has been partially supported by the EU FP7 Marie Curie IAPP project DIVeFor ”Digital Image and Video Forensics” (Grant Agreement No. 251677)

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