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DATA HIDING BY USING WATERMARKING TECHNIQUE ON HIGH DYNAMIC RANGE IMAGES

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ABSTRACT

High dynamic range (HDR) imaging techniques address the need to capture the full range of color and light that the human eyes can perceive in the real world. HDR technology is becoming more and more pervasive. In fact, most of the cameras and smartphones available on the market are capable of capturing HDR images. Among the challenges posed by the spread of this new technology there is the increasing need to design proper techniques to protect the intellectual property of HDR digital media. In this paper, we speculate about the use of watermarking techniques to cope with the peculiarities of HDR media to prevent the misappropriation of HDR images.

KEYWORDS

high dynamic range, data hiding, watermarking, low dynamic range.

I. INTRODUCTION

High dynamic range (HDR) imaging technologies provide a step forward in representing real scenes as they are perceived by the human eye. With respect to traditional imaging techniques capable of acquiring low dynamic range (LDR) images or video, HDR methodologies [1, 2] are capable of generating and rendering images and videos with a ratio between the luminance of the lightest and darkest areas far greater than the one provided by standard imaging technologies. It is evident that HDR media are richer in terms of content than their LDR counterparts and therefore much more valuable. It is therefore crucial to provide, since the early stages of the development of such technology, proper tools for protecting the intellectual property of digital HDR media. Data hiding, and more specifically digital watermarking [3, 4, 5], has emerged in the last decade as an enabling technology for copyright protection among other possible applications. Roughly speaking, data hiding is the general process by which a discrete information stream, the mark, is merged within media content by imposing imperceptible changes on the original host signal, while allowing the message to be detected or extracted even in the presence of either malevolent or non-intentional attacks. Other requirements, other than the transparency one, can be needed according to the specific application that is taken into account. Although LDR image or video digital watermarking is a very mature area of research, watermarking in an HDR scenario is still in its infancy and needs to be significantly developed. In this paper, we crystallize the state of the art on HDR image watermarking techniques and the watermarking embedding method proposed by the authors in [6] is more extensively tested using a wider set of images as well as up to date metrics for performance assessment.

II. MULTIMEDIA DIGITAL WATERMARKING

In the past decades, 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, data hiding and more specifically digital watermarking techniques [3, 4] have been proposed to address the ever-growing need to protect the intellectual property of multimedia content (digital still images, 2D and 3D video sequences, text, or audio) in the World Wide Web. Although copyright protection was the very first application of watermarking, different uses have been proposed in the 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. 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-malevolent signal processing (i.e., filtering and compression) are applied on the multimedia data. This requirement is known as watermark security. On the other hand, when the watermark is required to be resistant only to non-malicious manipulations, the watermarking techniques are 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. In some applications, the watermarked host data are intended to undergo a limited number of signal processing operations. Therefore, in the aforementioned scenario, the watermark needs to be robust only to a limited number of set of manipulations, in which case the technique is known as semi-fragile watermarking. 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. Robustness, imperceptibility, and capacity are requirements hindering each other; therefore, a trade-off driven by the application needs to be considered.

III. HDR IMAGE WATERMARKING: STATE OF THE ART

Despite digital watermarking of low dynamic range images having been deeply studied for more than two decades, watermarking of HDR media, both images and video, has not been extensively explored. In fact, a direct transposition of the techniques developed for LDR media is not straightforward since HDR media possess some peculiarities with respect to LDR ones which do not allow a direct transposition of the plethora of watermarking approaches already developed for LDR images and videos to the HDR case. In fact, the specific characteristics of the human visual system (HVS) related to the fruition of HDR media need to be exploited when designing HDR-tailored embedding techniques. Moreover, HDR-specific watermarking methods need to be robust against intentional attacks or signal processing manipulations like the use of tone-mapping operators (TMOs). The use of TMOs is necessary when HDR media need to be experienced 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 is highly desirable to design HDR watermarking schemes also robust against TMOs, thus allowing to either recover or detect the embedded mark not only from the marked HDR image but also from its tone-mapped version. In the following, an overview on the state of the art for HDR image watermarking is given. Specifically, in Section 3.1, the 1-bit embedding approaches are detailed, whereas the multi-bit approaches are summarized in Section 3.2.

3.1 HDR image watermarking: 1-bit embedding

Watermarking techniques aimed at embedding 1 bit of information imply the detection of the embedded watermark at the receiving side. In [7], two different watermarking methods, both of them splitting the cover HDR image into a host image where to embed the mark and a residual part, are investigated. The first approach employs the μ-law to characterize a generic TMO and applies it to the original HDR image to derive an LDR representation where the watermark can be embedded. The residual part is given by the ratio between the HDR and the LDR images. However, since the range of HDR images may be orders of magnitude greater than the one of LDR images, their ratio will be high in areas with high luminance, where the watermark will be therefore very strong. The second approach decomposes the HDR image into a detail and a coarse component by applying bilateral filtering. The watermark embedding is then performed in the detail component that preserves the images' edges. In fact, it is assumed that a generic TMO does not affect the image details and the color appearance, while addressing the problem of strong contrast reduction. Both methods proposed in [7] project the luminance of the detail component in the discrete wavelet domain. Then, the embedding is performed using spread-spectrum (SS) techniques. The experimental tests, conducted using five HDR images and four local TMOs, show that the visual quality of images marked with the μ-law-based approach, evaluated by means of the peak signal-to-noise ratio (PSNR) computed over tone-mapped images, is better than the one associated with the method relying on bilateral filtering. Specifically, the PSNR of the images marked with the first approach is within the 50–70-dB range, while the second one results in a PSNR of about 30–60 dB. However, bilateral filtering guarantees better performance in terms of robustness to the application of TMOs.

In [8], a general tone-mapping, represented by the logarithm function, is considered and applied to the luminance of the given HDR image, thus obtaining the LogLuv domain. The watermark embedding is performed by applying a quantization-index-modulation (QIM) approach [9] to the approximation subband of the discrete wavelet transform of the LogLuv component. 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 non-uniformly quantized value determined by the bit to be embedded into the block. Mark imperceptibility is obtained by applying a local perceptual mask based on luminance, texture, and contrast that provides the maximum amount of distortion that each coefficient in the embedding domain can withstand without resulting in visible artifacts. Experimental tests conducted on 15 HDR images include an objective analysis on mark imperceptibility evaluated through the HDR-Visual Difference Predictor (HDR-VDP) metric [10] and on the robustness of watermark detection against seven different TMOs as well as to the addition of Gaussian noise in the HDR domain.

In [11], a non-linear hybrid embedding approach operating in the detail subbands of a one-level wavelet decomposition is used to watermark an HDR image. Specifically, the approach combines both additive and multiplicative watermark embedding and is based on a square-root embedding equation operating in the wavelet domain. The embedding approach is applied to 12 images, and its robustness is tested against the application of seven TMOs. The quality assessment is carried out using both the HDR-VDP metric and a pool of three observers on a native HDR display.

In [12], a bracketing approach mimicking the HDR image generation process, consisting of merging several single-exposure LDR images, is exploited for HDR image watermarking. In details, an HDR image is split into multiple LDR images, which are watermarked before being fused again into a single HDR image representation. The mark embedded in the HDR image thus generated results to be detectable in its LDR counterparts obtained by either applying a tone-mapping process or extracting and displaying only a specific range of interest of intensities. The HDR-VDP-2 metric [13] is employed to assess the performance. An equal error rate (EER) lower than 10^{-8} % is achieved when detecting a watermark from LDR images obtained with five different TMOS. EERs lower than 10^{-2} % are estimated when analyzing LDR images obtained by isolating, from the HDR data, a dynamic range different from the one considered during embedding.

TABLE 1: SHOWING THE SUMMARY OF VARIOUS AUTHORS WITH RESPECT TO VARIOUS PARAMETERS

Paper	Embedding domain	Embedding method	# of images database	Imperceptibility	Robusteness
					4 TMOs
Xue et al. [7]	μ-law and wavelet	Multiplicative	5[a]	PSNR on LDR ∼ 55 dB	Score > threshold at
					$P_{fa}=10^{-8\%}$
	Bilateral and wavelet	Multiplicative		PSNR on LDR ∼ 45 dB	Score > threshold at
					$P_{fa}=10^{-8\%}$
					7 TMOs
Guerrini et al. [8]	LogLuv and wavelet	QIM	15[a, b]	HDR-VDP $_{75}\sim 0.46\,\%$	$P_{miss}=10^{-2}$ % at
					$P_{fa}=10^{-6\%}$
				HDR-VDP $_{95}\sim 0.21\,\%$	Add. noise
					$P_{miss}=10^{-12}$ % at
					$P_{fa}=10^{-6\%}$
Autrusseau et al. [11]	Wavelet	Hybrid	5, 7[a, b]	HDR-VDP	8 TMOs
				Subjective (3 subjects)	qualitative analysis
Solachidis et al. [12]	Wavelet	Additive	6[a]	HDR-VDP-2 $_{95}\sim 5.00\,\%$	6 TMOs

3.2 HDR image watermarking: multi-bit embedding

In [14], binary information is inserted into an HDR image encoded in RGBe format by substituting the least significant bits (LSBs) of each pixel with bits taken from the secret message. In more detail, 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, embedding more bits in high contrast and dark regions than in smooth and bright ones. The method capacity, tested on seven HDR images, is around 10 bits per pixel (bpp). 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 30 dB.

Images in uncompressed LogLuv TIFF format are considered in [15]. 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 the resulting images is evaluated over seven HDR images by applying tone-mapping and computing the PSNR and the HDR-VDP metrics.
The RGBe format is considered in [16], where its property of expressing a given color according to different possible choices is employed to hide a message into an HDR image: the final color representation is selected among the equivalent ones on the basis of the bits of the secret message. Such an approach produces distortion-free watermarked images, being different with the original cover image due only to the conversion employed to determine the floating point value of the pixels. A capacity of about 0.12 bpp is estimated over five HDR images.
The blue component of a detail layer obtained exploiting bilateral filtering as in [7] is employed in [17] to embed into an HDR image binary messages with as many bits as the image's pixels. The mark is inserted additively yet proportionally to the pixels' luminance. The mark imperceptibility is measured only through the PSNR, evaluated over five HDR images, achieving values around 60 dB. No objective measurements of mark extraction capability are provided, and the robustness against TMO is not evaluated. It is worth noting that no intentional or unintentional attack is taken into account in any of the aforementioned approaches performing multi-bit message embedding.

IV. CONCLUSIONS
HDR images represent valuable content, whose intellectual property needs to be protected by means of proper digital techniques. To this aim, a blind multi-bit watermarking method for HDR images has been presented in this paper. The proposed approach hides information in areas closely associated to image contours, thanks to the properties of the considered RDCT transform. The selected embedding domain guarantees proper imperceptibility of the inserted marks, while providing the means for blindly extracting the embedded information without the need of the original image. An extensive set of experimental tests, conducted on 15 different HDR images, has been conducted to estimate the performance of the proposed method. The HDR-VDP-2 metric is employed to evaluate the perceptibility of the performed modifications, while six different TMOs have been employed to evaluate the possibility of retrieving the embedded data from LDR images generated from the marked HDR ones. The effects of signal processing attacks such as Gaussian additive noise and filtering have been also evaluated. The obtained results testify the effectiveness of the proposed approach, also showing the trade-off relationships between imperceptibility, robustness, and capacity when varying the parameters determining the employed system configurations.

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