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Robust Watermarking Framework for High Dynamic Range Images Against Tone-Mapping Attacks

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1. Introduction

1.1 Background explanation

As digital cameras become more and more popular recently, it is very easy for us to take many digital photos. Unfortunately, they are rarely true measurements of relative radiance in the scene due to the limited dynamic range in the image acquisition devices. High dynamic range (HDR) images emphasis in image processing fields because they can accommodate a greater dynamic range of luminance between the brightest and darkest parts of an image. Dynamic range is the ratio between the brightest and darkest luminance values of a scene. In general, human eyes can handle a very large dynamic range of approximately 100000:1 in a single view. However, a standard photo taken with a standard camera with film or an electronic imaging array always has a limited dynamic range [1]. A standard image, called a LDR image, cannot reproduce the luminance ratio observed in the real world. A scene containing very bright highlights and deep shadows always loses some detail if the exposure time is not suitably determined. Over the past decade, many researchers have developed HDR imaging techniques (Debevec & Malik, 1997)(Reinhard *et al*, 2005) (Reinhard *et al*, 2007). Debevec and Malik proposed a method to recover the single high dynamic range radiance map from multiple images with different exposure times (Debevec & Malik, 1997), this method has been implemented in many HDR software.

The reconstruction of a high dynamic range image is a complex process. Producing an HDR image is by capturing multiple images of the same scene with different exposure levels and merging them into a single HDR image (Debevec & Malik, 1997). The photographers can use a tripod in order to capture the same scene and avoid image registration problems. However, if the differently exposed image sequences are took hand-held, an image registration method which is robust to the illumination changes and moving objects should be used to align the multiple input images before HDR image composition. In addition, the user must be able to use the exposure bracketing technique to ensure the pictures are properly exposed.

1.2 Research motivation

Obviously, it is quite an achievement to create a high dynamic range image containing pixel values that span the whole tonal range of real world scenes. It takes efforts not only to capture the differently exposed photographs as input, but also to reconstruct high dynamic range image by the techniques of image registration and image composition. The copyright protection for HDR images has become increasingly important.

Image watermarking is a common method of proving ownership or determining origin (Tsang & Au, 2001). Unintentionally destroyed watermarks happen when transmitting an image. Since pirates may also seek to remove the watermark or make it undetectable, the watermark must be robust to common attacks. Some of the common problems include noising, blurring, cropping and geometric distortions. Several watermarking schemes embed the watermark in the transformed domain (Piva *et al*, 1997)(Barni *et al*, 1999)(Wang *et al*, 2002) (Suhail. & Obaidat, 2003), which is robust to common image processing attacks, such as low-pass filtering or JPEG compression. However, the watermarking methods in the literature paid attention on the conventional LDR images, they can not be applied to the high dynamic range images.

1.3 The purpose of research

The challenge of the watermarking techniques for high dynamic range images is the tone mapping operators in which we usually use them to convert a high dynamic range image to the conventional low dynamic range image. Tone mapping is necessary for rendering an HDR image on low dynamic range devices such as standard screens or printers. This chapter presents a new watermarking framework for HDR images to alleviate the problem of tone mapping distortions. To demonstrate the powerfulness of the proposed method, a simple DCT-based watermarking technique for conventional LDR images is used. We embed the watermarking in the middle frequency DCT coefficients of the tone-mapped LDR image, the ratio image is then multiplied to recover the HDR values, where the ratio image is computed by dividing the original HDR image at each pixel by the tone-mapped luminance. Experimental results shows the watermarked HDR image keeps high visual quality and the embedded watermark using the proposed technique is robust to varying degree to tone mapping distortions, low-pass filtering, noise contamination and cropping.

2. HDR watermarking technique for HDR images

This section presents an efficient and robust watermarking algorithm for high dynamic range images. Using this blind watermarking algorithm, the watermark extraction is without the original image. The most common process for HDR images is tone mapping. Tone mapping HDR images to LDR images reveals highlights and shadow details on standard LDR devices. The aim of the proposed method is to develop a watermarking scheme against the process of tone mapping.

2.1 Watermark embedding

The key idea of the proposed method is triggered by a sub-band encoding algorithm for high dynamic range images (Ward & Simmons, (2004), the new lossy HDR high dynamic range image format is backwards compatible with existing JPEG software. A tone-mapped

version of HDR original image is accompanied by restorative information in the standard 24-bit RGB format. This sub-band in JPEG format contains a compressed ratio image, which can be used to recover the original high dynamic range image by multiplying the tone-mapped foreground by the ratio image. Figure 1 illustrates the flowchart of the proposed watermark embedding framework for high dynamic range images.

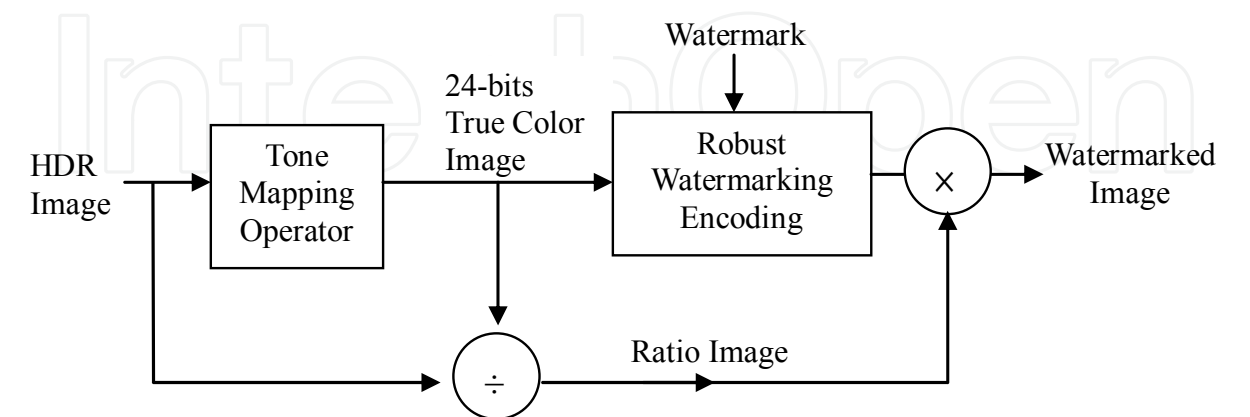


Fig. 1. Illustration of the proposed watermark embedding process for high dynamic range images.

A tone-mapped LDR image is first generated by a tone-mapping operator from the original high dynamic range image. A ratio image is then obtained by dividing the HDR image by the tone-mapped LDR image. Any conventional watermarking technique for LDR images can be applied to embed the watermark bits into the tone-mapped LDR image. Finally, by multiplying the watermarked image by the ratio image, the HDR image with watermark is then obtained. Due to the watermark is embedded in the tone mapped LDR image, the proposed HDR watermarking scheme is robust against the tone mapping attacks.

Discrete cosine transform (DCT) is widely used in signal and image processing for lossy data compression. To demonstrate the powerfulness of the proposed HDR image watermarking scheme, a simple DCT-based watermarking method is adopted to embed the watermark into the tone-mapped LDR image. We transformed the LDR image into the frequency domain and embedded the watermark into the lower middle-frequency blocks, for example the coefficient $DCT_{3,3}$ of each 8×8 image block. We used a neighboring difference-based method to embed the watermark as shown in Table 1, where X denotes a block $DCT_{3,3}$, Y denotes its neighboring block $DCT_{2,4}$, and X' denotes the X block after the bit is embedded. If the watermark bit is 1, X' is set to be larger than or equal to Y . If the bit is 0, X' is set to be smaller than Y . After embedding the watermark, the watermarked LDR image is obtained by inversely transforming from the modified DCT image. It is obvious that the modification is invisible and the watermark is robust to various common attacks, such as blurring and noising and cropping. Finally multiplying the watermarked LDR image by the ratio image produces the watermarked high dynamic range image.

To improve the security to the proposed watermarking technique, the index table of the watermark is disturbed by a 1-D binary pseudo-random sequence using the private key as seed. The encrypted watermark is then embedded into the tone mapped LDR image and yields the watermarked HDR image using the procedure shown in Fig. 1.

W = 0		W = 1	
if $X \geq Y$	$X' = Y - diff$	if $X \geq Y$	$X' = X + diff$
if $X < Y$	$X' = X - diff$	if $X < Y$	$X' = Y + diff$

Table 1. DCT-based watermark embedding algorithm.

2.2 Watermark extraction

Figure 2 shows the flowchart for extracting the watermark. We first use the tone mapping operator to convert the corrupted watermarked HDR image to the watermarked LDR image. The watermark detection method for conventional LDR image is then used to blindly extract the watermark bits without the original HDR image. The watermark is decrypted by the secrete private key.

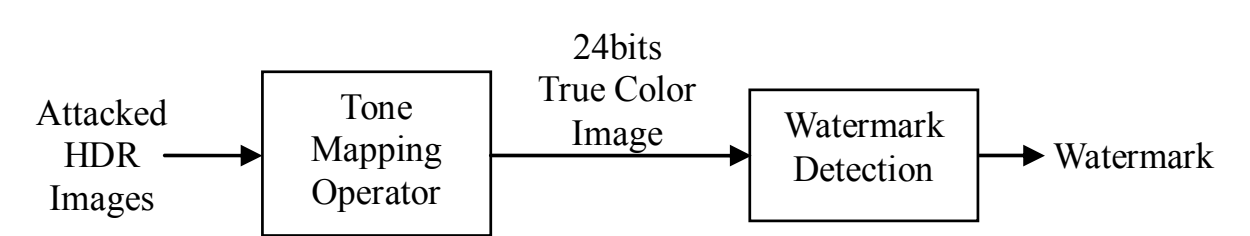


Fig. 2. The flowchart of the HDR image watermark retrieving procedure.

3. Experimental results

Several HDR images are used in the experiments to verify the proposed HDR image watermarking algorithm. The watermark used in this chapter is the 80×60 logo watermark as shown in Fig. 3. We applied several common signal processing attacks to the watermarked HDR images to evaluate the proposed watermarking scheme.



Fig. 3. The logo watermark used in the experiments.

To quantify the robustness of the proposed algorithm, we computed the value of the normalized correlation (NC) coefficient between the original watermark and the extracted one to measure the quality of the retrieved watermark bits, the formula is shown below:

$$\rho(W,W') = \frac{\sum_{m=1}^{N_w} w_m w'_m}{\sqrt{\sum_{m=1}^{N_w} w_m^2 \sum_m w_m'^2}} , \tag{1}$$

where W and W' denote the embedded watermark and the extracted watermark respectively and N_w is the length of the watermark. The coefficient is bounded by $-1 \leq \rho(W, W') \leq 1$. Since the watermark is a binary sequence of ± 1 , we have

$$\sum_{m=1}^{N_w} w_m^2 = \sum_{m=1}^{N_w} (w'_m)^2 = N_w \quad (2)$$

The normalized correlation coefficient can also be written as

$$\rho(W, W') = \frac{\sum_{m=1}^{N_w} w_m w'_m}{N_w} \quad (3)$$

A larger ρ indicates a better retrieval performance.

Figure 4 shows a high dynamic range image –hot spring, which is recovered from six LDR photographs with different exposure time, the image size is 640×480 . It is used for experiments to prove the robustness of the proposed method against common signal processing attacks on the watermarked HDR image. We first converted the original HDR image to its corresponding LDR image using a tone mapping operation and then computed the ratio image. The dynamic range compression algorithm based on fast bilateral filtering (Durand & Dorsey, 2002) is used as the tone mapping operator in the watermark embedding procedure. A simple DCT- based watermarking method is then used to embed the logo watermark shown in Fig. 3 into the tone mapped LDR image.

Figure 4 shows a high dynamic range image –hot spring, which is recovered from six LDR photographs with different exposure time, the image size is 640×480 . It is used for experiments to prove the robustness of the proposed method against common signal processing attacks on the watermarked HDR image. We first converted the original HDR image to its corresponding LDR image using a tone mapping operation and then computed the ratio image. The dynamic range compression algorithm based on fast bilateral filtering [10] is used as the tone mapping operator in the watermark embedding procedure. A simple DCT- based watermarking method is then used to embed the logo watermark shown in Fig. 3 into the tone mapped LDR image.

Figure 5(a) depicts the tone mapped LDR image, and the watermarked LDR image is shown in Fig. 5(b). This figure shows that the two images are visually indistinguishable and the peak signal-to-noise ratio (PSNR) value between them is 41.48 dB. Finally the watermarked HDR image is produced by multiplying the watermarked LDR image by the ratio image.

Table 2 shows the result of the watermarked high dynamic range image corrupted by cropping, blurring and noising attacks. The normalized correlation coefficient between the extracted and original watermark are all higher than 0.3, and the extracted watermarks are distinguishable. It shows the effectiveness of the proposed HDR watermarking algorithm.

Mean square error (MSE) is not a good performance index to measure the difference between the original high dynamic range image and the watermarked one, it is because that the intensity range of the high dynamic range radiance map recovered by different approaches or programs are quite varying. In order to provide a fair measurement to the

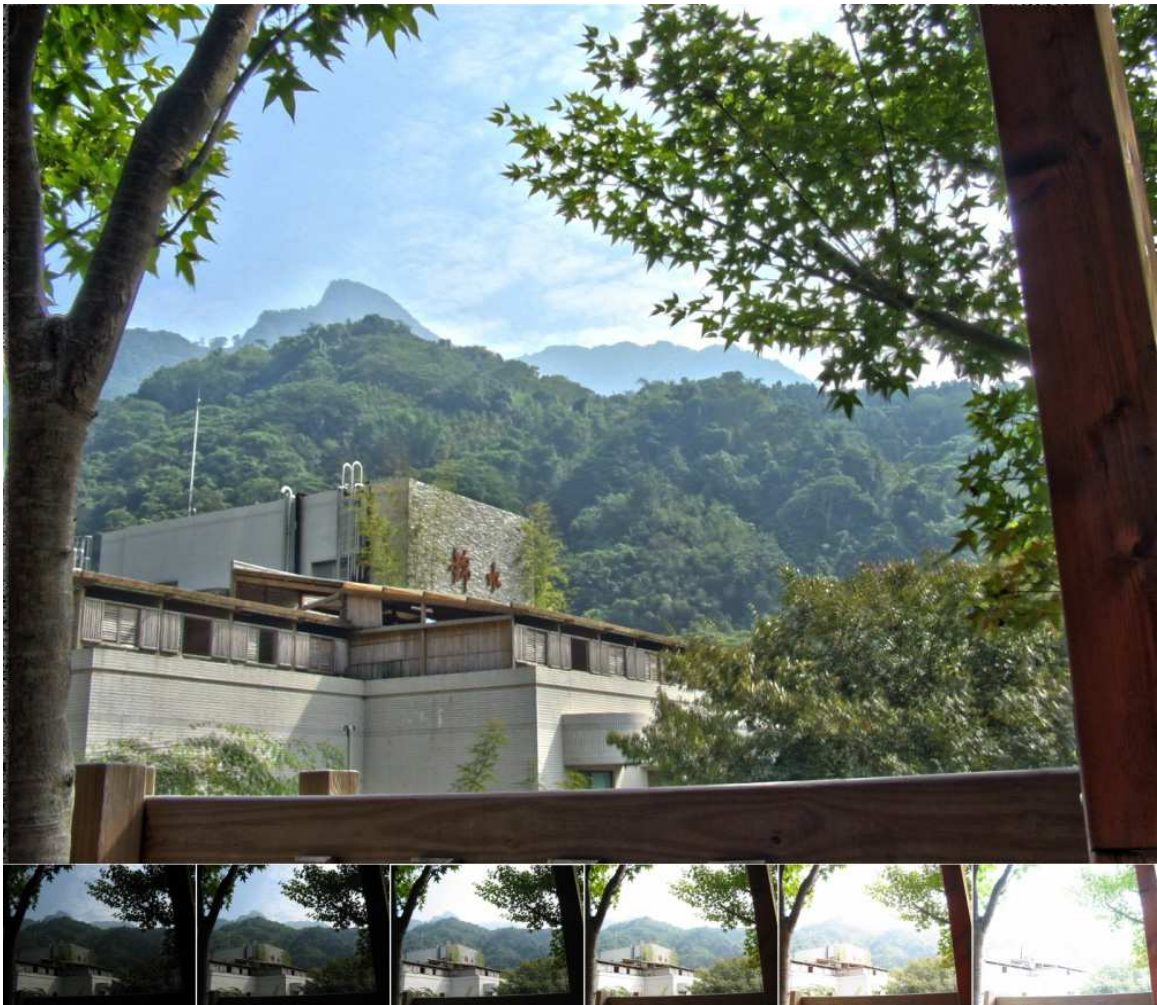


Fig. 4. A high dynamic range image, hot spring, reconstructed from six differently exposed photographs.

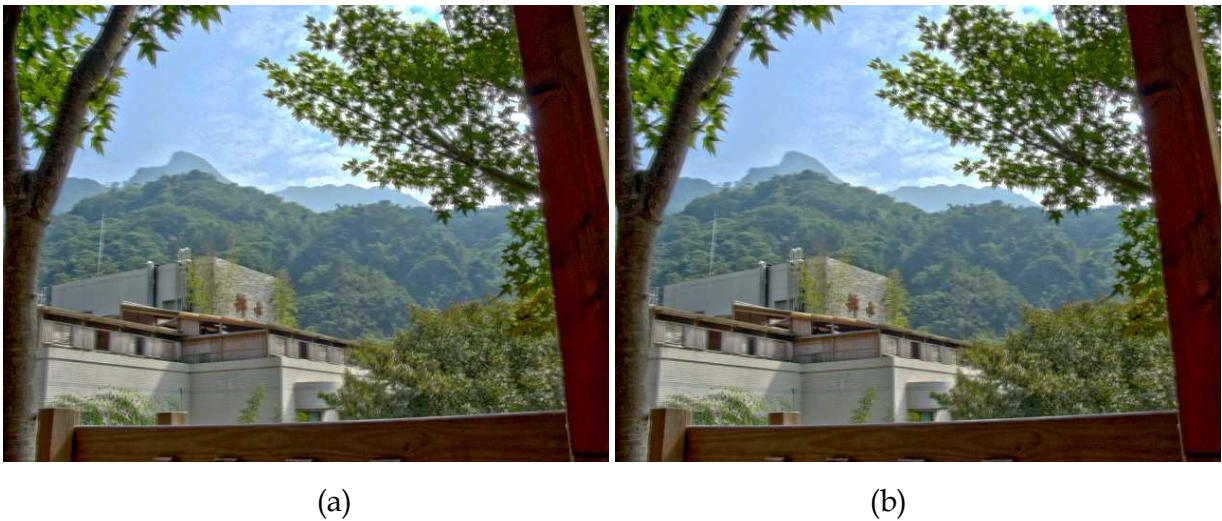


Fig. 5. Tone mapped LDR image and its watermarked version. (a) The tone mapped LDR image using the bilateral-filter based algorithm. (b) The watermarked LDR image by the DCT-based watermarking method.


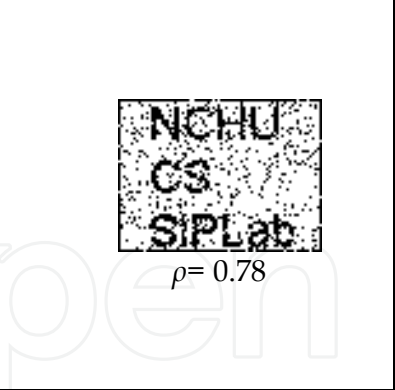

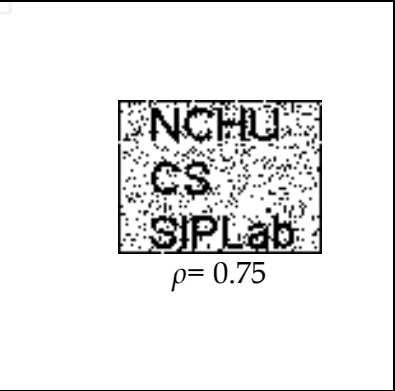

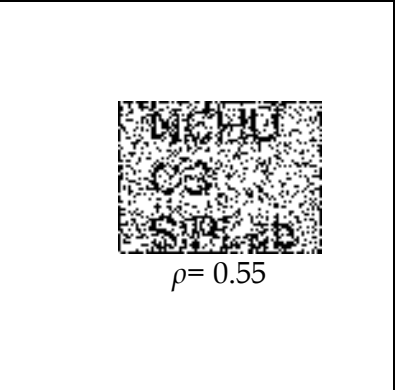

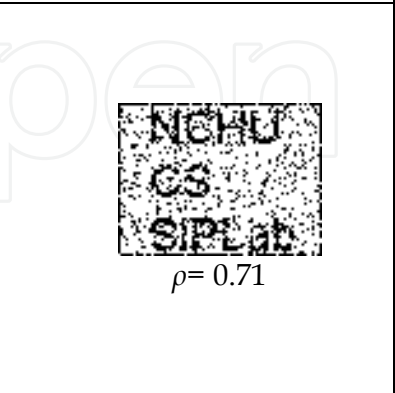
Distortion attack	Tone-mapped LDR image	Extracted watermark
Cropping 1		
Cropping 2		
Gaussian blur (radius=0.8)		
Addaptive Gaussian noise (variance=9)		

Table 2. The extracted watermark and the correlation coefficient ρ upon common signal processing attacks – cropping, blurring and noising.

quality of the watermarked high dynamic range image, we propose to normalize the original high dynamic range image to the range $[0, 255]$ in the experiments, the peak signal-to-noise ratio (PSNR) is then calculated to measure the distortion between the original HDR image and the watermarked one, the formula is shown in Eqs. (4) and (5).

$$PSNR = 10 \cdot \log_{10} \left(\frac{255^2}{MSE} \right) \text{ dB} \quad (4)$$

and

$$MSE = \frac{1}{3WH} \sum_{x=1}^W \sum_{y=1}^H \sum_{c \in \{R,G,B\}} (O_c(x,y) - I_c(x,y))^2 \quad (5)$$

where W and H are the total number of pixels in the horizontal and the vertical dimensions of the images; $O_c(x,y)$ and $I_c(x,y)$ denote the pixels of the original and watermarked image respectively. According to our experience, the distortion for the high dynamic range images is invisible if the PSNR of the normalized HDR image is higher than 55 dB.



Fig. 6. A high dynamic range image- Belgium house (Fattal, *et al.*, 2002), the image size is 1024×760 .

The algorithms that preparing HDR images for display on LDR devices are called tone mapping operators or tone reproduction. Three famous and popular tone mapping algorithms include the fast bilateral filter approach proposed by Durand and Dorsey [10], photographic method by Reihard. (Reihard. *et al.*, 2002), and the gradient domain compression (GDC) algorithm by Fattal. (Fattal *et al.*, 2002). Just as described in previous section, tone mapping is the most often used attack for high dynamic range images. To evaluate of the robustness of the proposed method against the tone mapping attacks, all three approaches mentioned above are used to test the proposed watermarking algorithm. In this experiment, a high dynamic range image - Belgium house as shown in Fig. 6 is used , which is obtained from the work of Fattal (Fattal *et al.*, 2002), and its size is 1024 by 760.

The PSNR of the watermarked HDR image using the bilateral filtering method [10], photographic method (Reihard. *et al.*, 2002), and the gradient domain compression (GDC) algorithm in the watermark embedding procedure are 77.58, 77.36 and 73.00 respectively. We observed that the watermarked high dynamic range image by using the GDC as the tone mapping operator in the watermark embedding step produced higher distortion compared two other tome mapping approaches. However, the visual quality is still satisfied and the PSNR is much higher than 55dB. Table 3 shows the performance comparison of the different tone mapping operators are used in the watermark embedding and retrieving procedures. It is worthy to notice that the watermarked HDR image using GDC in the watermark embedding procedure perform best against the various tone mapping attacks.

Table 4 shows the robustness comparison of the watermarked HDR image when different tone mapping methods are used in the watermark embedding procedure. Two common signal processing attacks- blurring and cropping are corrupted on the watermarked HDR image. It shows the watermarking method used GDC method achieves the highest normalized correlation coefficient. In the following experiments, we adopt GDC as the tone mapping operator in the proposed HDR watermark embedding procedure.

Finally, two another high dynamic range images obtained from Debevec's work (Debevec & Malik, 1997) are used to verify the proposed watermarking method, as shown in Fig. 7. Table 5 and 6 show the results, they demosntrate the effectivenss and robust ness of the proposed method.

4. Conclusion

Researching the watermarking scheme for high dynamic range images is an important task in image processing and computational photography fields. This chapter presents a new blind watermarking algorithm for HDR images. It achieves the robustness by embedding the watermark bits into a tone mapped version of the original HDR image. Experimental results show that the proposed algorithm is robust against various tone mapping operations, which is an inherent problem in watermarking HDR images. A simple DCT-based watermarking method for the derived tone-mapped LDR image is used in the watermark embedding procedure, it protects the watermarked HDR image from several common signal processing attacks, including noising, blurring and cropping. In the future work, the geometric attack invariant features will be put into analysis to enhance the robustness. Meanwhile, the capacity and fidelity are also taken into account.

Embedding		Photographic	Bilateral	GDC	
Retrieving	Photographic		0.87	0.82	0.90
	Bilateral		0.83	0.83	0.87
	GDC		0.88	0.87	0.92

Table 3. The comparison of the different tone mapping operators are used in the HDR watermark embedding and retrieving procedures.



Fig. 7. Two high dynamic range images (Debevec & Malik, 1997). (a) indoor; (b) church window.




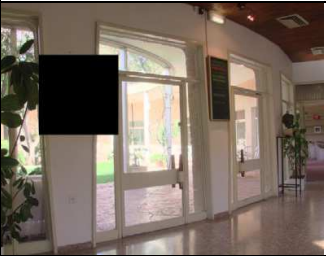
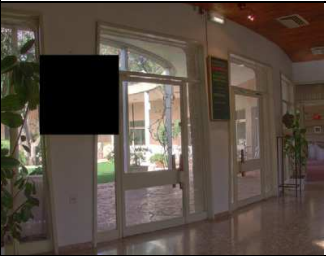

Embedding Distortion		PhotoGraphic	Bilateral	GDC
Bluring	Tone mapped corrupted image			
	PSNR of distorted HDR image	40.18	40.18	40.18
	NC of the retrieved watermark	$\rho = 0.72$	$\rho = 0.68$	$\rho = 0.78$
Local cropping	Tone mapped corrupted image			
	PSNR of distorted HDR image	35.46	35.46	35.46
	NC of the retrieved watermark	$\rho = 0.72$	$\rho = 0.69$	$\rho = 0.75$

Table 4. The comparison of the robustness of the watermakre HDR image when different tone mapping methods are used in the watermark embedding procedure under bluring and cropping attacks.

Distortion	PSNR of the corrupted HDR image (dB)	Correlation coefficient ρ of the extracted watermark
Tone mapping by Bilateral approach	61.51	0.86
Tone mapping by photographic method	59.78	0.83
Gaussian blurring (radius=0.8)	36.19	0.71
Blurring + cropping	54.40	0.80

Table 5. The watermarking result using the HDR image-indoor.

Distortion	PSNR of the corrupted HDR image (dB)	Correlation coefficient ρ of the extracted watermark
Tone mapping by photographic method	43.34	0.94
Gaussian blurring (radius=0.8)	28.31	0.74
Cropping	31.33	0.74
Blurring + cropping	26.61	0.55

Table 6. The watermarking result using the HDR image-church window.

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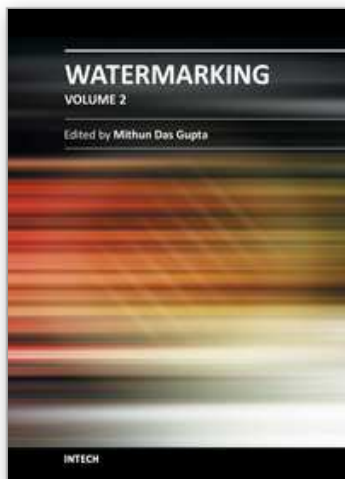
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Watermarking - Volume 2

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This collection of books brings some of the latest developments in the field of watermarking. Researchers from varied background and expertise propose a remarkable collection of chapters to render this work an important piece of scientific research. The chapters deal with a gamut of fields where watermarking can be used to encode copyright information. The work also presents a wide array of algorithms ranging from intelligent bit replacement to more traditional methods like ICA. The current work is split into two books. Book one is more traditional in its approach dealing mostly with image watermarking applications. Book two deals with audio watermarking and describes an array of chapters on performance analysis of algorithms.

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