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Technical Section

High-order wavelet reconstruction for multi-scale edge aware tone mapping ☆

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ABSTRACT

This paper presents a High Order Reconstruction (HOR) method for improved multi-scale edge aware tone mapping. The study aims to contribute to the improvement of edge-aware techniques for smoothing an input image, while keeping its edges intact. The proposed HOR methods circumvent limitations of the existing state of the art methods, e.g., altering the image structure due to changes in contrast; remove artefacts around edges; as well as reducing computational complexity in terms of implementation and associated computational costs. In particular, the proposed method aims at reducing the changes in the image structure by intrinsically enclosing an edge-stop mechanism whose computational cost is comparable to the state-of-the-art multi-scale edge aware techniques.

1. Introduction

High Order Reconstruction (HOR) methods, introduced by Harten et al. [1], have been used extensively for solving the hyperbolic conservation laws and the Hamilton-Jacobi equations [2]. Additionally, these methods have been applied to image processing (image compression), denoising [3] and segmentation [4]. Due to their ability to reduce oscillations around function discontinuities, these methods can be potentially used as an edge aware interpolation tool. Edge-aware techniques such as anisotropic diffusion [5], bilateral filtering [6,7] and neighborhood filtering rely on sophisticated type of spatially varying kernels. Often, they tend to either generate artificially staircasing effects or ringing effects around sharp edges [8]. These artifacts can be reduced using a post-processing step at the price of increasing the computational cost and the number of parameters used [9]. To have better control of the details over the spatial scale, one can apply edge-aware techniques in a multi-scale fashion. However, the bilateral filtering is inappropriate for multi-scale detailed decomposition [10]. Other edge-aware techniques that support the multi-scale approach [10,11,9] also encompass some flaws, e.g., they are not able to achieve a plausible reproduction of all important image features [12] and may change the image structure.

Therefore, there is a need to develop methods that are reducing as much as possible any change into the image structure without increasing the complexity or computational cost.

In this paper, we link the edge-aware problem to the typical problem of interpolation. In particular, we propose a novel wavelet scheme that uses a robust predictor operator, based on the HOR method, which intrinsically encloses an edge-stop mechanism to avoid influence of pixels from both sides of an edge. To have a better control of details over the spatial scale, we employ the HOR method in conjunction with a multi-scale scheme.

We demonstrate the usability of the proposed method to solve a typical problem in the context of High Dynamic Range (HDR) imaging, called tone mapping as defined in Banterle et al. [13].

The approach is formulated as follows; we decompose an input HDR image, making use of wavelet decomposition and through the use of HOR methods separate its coarse and fine features (details). The coarse and fine features are then manipulated to achieve the desired tone and details levels. Finally, the output image is reconstructed. The advantage of the above approach is that it does not require the introduction of any edge-stopping function that limits possible image-structure changes.

To understand this concept, Fig. 1 shows the distortion map as output of the Dynamic Range Independent metric (DRIM)

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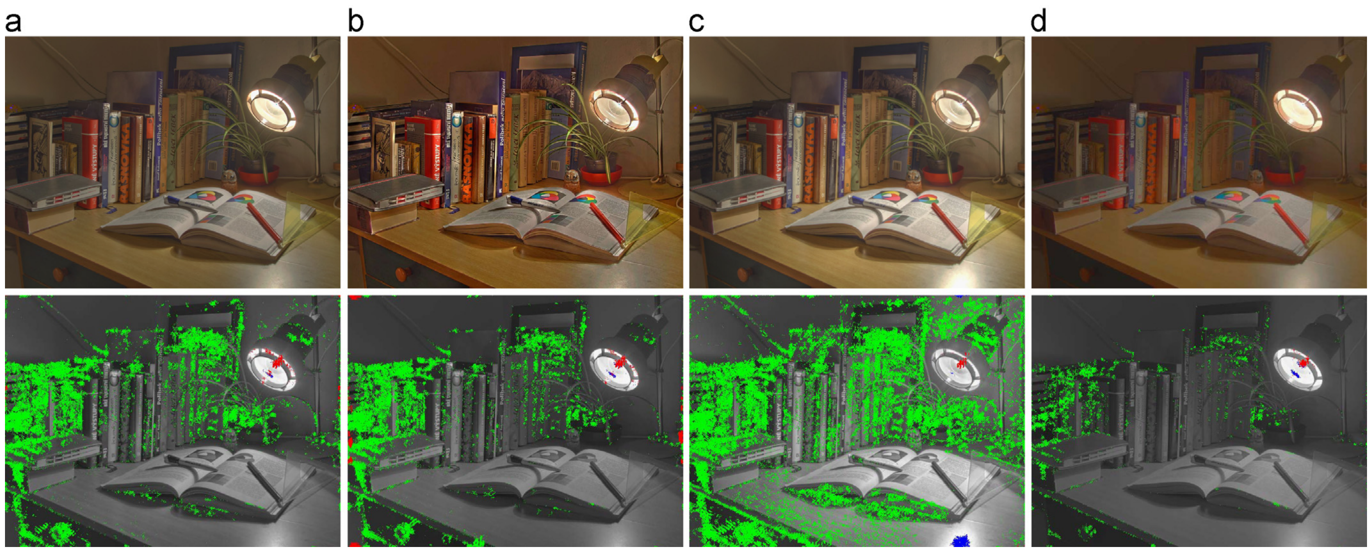

Fig. 1. Comparison of the state-of-the-art multiscale edge aware based tone mapping operators and the present HOR: 1st row: output of the various techniques. 2nd row: distortion map of the DRIM metric [12]. This map is showing the pixels that shows a distorsion with 95% of probability to been seen by the Human Visual System (*HVS*). Blue pixels are areas where invisible contrast is introduced; red pixels are areas where reversal of visible contrast is noticeable and green pixels shows areas of lost of contrast. The map is showing of a reduction of more than 50% of the pixels affected by loss of contrast when the HOR method is used. Parameters used - (a) Farbmann et al. [10] multiscale approach balanced - (b) Fattal's [11] $\alpha=0.9$, $\beta=0.16$ and $\gamma=0.8$ - (c) Paris et al. [9] $\sigma_r=\log(2.5)$, $\alpha=0.5$ and $\beta=0.0$ (for conveying the local effect) - (d) the present HOR $\beta=0.7$, $\gamma=0.9$. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

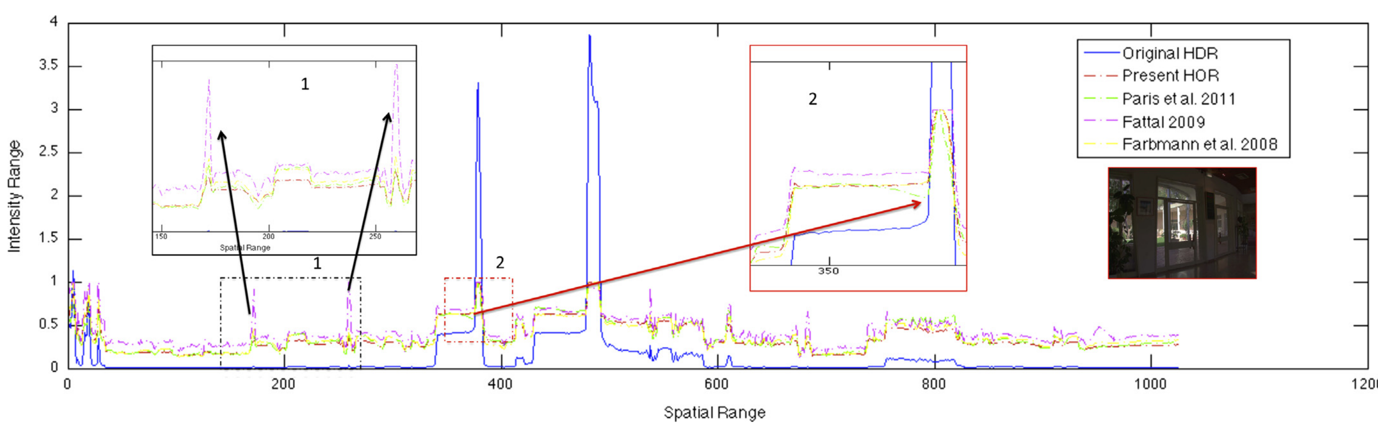

Fig. 2. Intensity profile for the tone mapping operators on an HDR mage for line 300: The 1st zoomed area, clearly shows how Fattal's [11] method (undesirably) increases the intensity profile to the maximum value of 1. In the 2nd zoomed area (Paris et al. [9] green line), the intensity profile is modified. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

introduced by Aydin et al. [12] for [10,11,9] and the technique proposed in this paper. The original HDR image is used as reference, and the output of the tone mapping operator is compared to it. A certain amount of lost of contrast (green) is clearly visible, and this may change the overall image structure [12]. The map shows that using the present HOR reduces the number of pixels affected by loss of contrast by more than 50%.

Moreover, the intensity profile may change as shown in Fig. 2. The Fattal method [11] may have an undesirable increase of the intensity profile to the maximum output value 1 (1st zoomed area). The structure of the original profile may be undesirably modified (green line) as shown for the method [9] (2nd enlarged area). These methods may result in prohibitive computational costs (see Paris et al. [9]). An efficient implementation [14] of the method presented by Paris et al. [9] is also discussed in Section 6.

The proposed approach retains the same advantages introduced by the traditional edge aware approaches such as Paris et al. [9], and Fattal [11], namely with respect to obtaining local properties and providing robust smoothing, hence avoiding the use of pixels from both sides of the edge. The main contributions of this work can be summarized as follows:

1. Establish a link between the robust smoothing concept to the reconstruction problem of a non-smoothed function.
2. Achieve a complex solution of the edge-aware problem, through a simple and flexible point-wise manipulation by using HOR method.
3. Propose an edge-aware filter that produces halo free results; reduces the changes in the image structure as defined by the DRIM metric and its computational cost is increasing linearly with respect to the number of the input pixels N.

2. Related work

Edge aware filters: Edge aware techniques are used to smooth an image while keeping its edges intact, preventing pixels located