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On performance of lossless compression for HDR image quantized in color space

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ABSTRACT

High dynamic range (HDR) image requires a higher number of bits per color channel than traditional images. This brings about problems to storage and transmission. Color space quantization has been extensively studied to achieve bit encodings for each pixel and still yields prohibitively large files. This paper explores the possibility of further compressing HDR images quantized in color space. The compression schemes presented in this paper extends existing lossless image compression standards to encode HDR images. They separate HDR images in their bit encoding formats into images in grayscale or RGB domain, which can be directly compressed by existing lossless compression standards such as JPEG, JPEG 2000 and JPEG-LS. The efficacy of the compression schemes is illustrated by presenting extensive results of encoding a series of synthetic and natural HDR images. Significant bit savings of up to 53% are observed when comparing with original HDR formats and HD Photo compressed version. This is beneficial to the storage and transmission of HDR images.

1. Introduction

Low dynamic range (LDR) images displayed on conventional screen are 24-bits, including 8-bits per color component (RGB). Therefore, there are totally 256 different intensity levels for each component. However, real-world dynamic range is far greater than 256 intensity levels. Also humans can simultaneously perceive contrast ratio of more than 4 orders of magnitude, and adapt their sensitivity up and down another 6 orders [8].

High dynamic range (HDR) images require a higher number of bits per color channel than traditional images. This brings about problems to storage and transmission. Color space quantization has been extensively studied to achieve bit encodings for each pixel [1]. The examples include LogLuv24, LogLuv32, RGBE, XYZE, EXR, srRGB, etc. None of these supports lossy compression and therefore these formats yield prohibitively large files.

In this paper, we study lossless compression for HDR images in their color space representation (note this is different from lossy compression algorithms which have been proposed by Refs. [14–16]). We focus here on lossless image compressions as opposed to bit encodings for each pixel. Paralleling conventional image formats, there are many HDR image formats to choose from [1]. In this paper, we employ two of the most popular ones, Radiance RGBE [9] and SGI LogLuv [10], for illustration although we believe that similar study can be applied to other formats. Transforming HDR images in these formats to RGB will lead to floating-point values, which are unfortunately not compatible to most coding standards. Therefore we select to compress HDR images in their RGBE or LogLuv domain. This means minimizing number of floating-point operations and therefore lowering complexity of encoding and decoding processes. A basic idea of designing a compression scheme is to apply an inter-pixel predictive scheme before entropy coding is used on the prediction error.

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However, existing image compression standards, such as JPEG [2], JPEG 2000 [3], JPEG-LS [4], etc., are widely available and supported. Clearly, we will be living with these formats for many years to come. Our chances of large scale adoption increase dramatically if we can maintain backwards compatibility with these standards [8]. Therefore, we adopt JPEG, JPEG 2000, JPEG-LS as compression tools in our study to achieve backwards compatibility. Note that in the rest of this paper, JPEG, JPEG 2000 and JPEG-LS will be used to refer to their lossless compression modes unless otherwise stated.

In Section 2, we briefly introduce the formats of RGBE and LogLuv, respectively. In Section 3, lossless compression standards JPEG, JPEG 2000 and JPEG-LS are reviewed. We study the applicability of applying the existing lossless image compression standards on HDR images quantized in color space in Section 4. Simulation results shown in Sections 5 and 6 concludes the paper.

2. HDR image encodings

HDR image encodings have been extensively studied and a comprehensive introduction is given in Ref. [1]. In this section, we only present two of them which will be employed for illustration purposes in the rest of this paper. The advantages and disadvantages of these two as well as other formats will not be discussed in details as the focus of this paper is exploitation of further lossless compression of HDR images which are already quantized in color space.

2.1. Radiance RGBE format

RGBE [1] is a simple format with free source code. It uses one byte for the red mantissa, one for the green, one for the blue, and one for a common exponent, as shown in Fig. 1. It provides 76 orders of magnitude in 1% steps. Run-length encoding is applied to achieve an average 20% compression ratio. This format does not cover visible gamut.

2.2. SGI LogLuv format

For Logluv, there are 24-bit encoding and 32-bit encoding. The 24-bit encoding leads to a 10-bit log luminance portion and a 14-bit indexed uv coordinate mapping. The 32-bit encoding uses 16-bits for luminance (1 bit for sign as 32-bit LogLuv allows negative luminance values) and 8 bits each for CIE(u,v), as shown in Fig. 2. The 32-bit encoding provides greater dynamic range and precision compared to the 24-bit version. What is more,

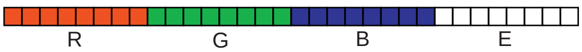

Fig. 1. RGBE format.

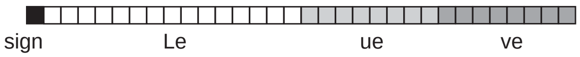

Fig. 2. 32-bit LogLuv format.

32-bit LogLuv images result in smaller file size than their 24-bit counterparts [10]. It provides 38 orders of magnitude of luminance in 0.3% steps. Run-length encoding is used to achieve an average 30% compression ratio. We adopt the 32-bit LogLuv encoding in the following discussion.

3. Lossless image compression standards

3.1. Lossless JPEG

Lossless JPEG was developed as a late addition to JPEG in 1993. It uses a completely different technique from the lossy JPEG standard. A predictive scheme based on the three nearest neighbors (upper, left, and upper-left) is used before entropy coding is applied on the prediction error [2]. Lossless JPEG has popularity in medical imaging [12].

3.2. Lossless JPEG 2000

Lossless JPEG 2000 [3] is based on a special integer wavelet filter, which is called biorthogonal 3/5. It runs more slowly and often has worse compression ratios on artificial and compound images than JPEG-LS [4], which will be introduced in next subsection. However, lossless JPEG 2000 is more widely supported and fares better than the UBC implementation of JPEG-LS on digital camera pictures [12].

3.3. JPEG-LS

JPEG-LS was developed aiming to provide a low complexity "near lossless" image compression standard that could be able to offer better compression efficiency than lossless JPEG. The core of JPEG-LS is based on the LOCO-I algorithm [5] that relies on prediction, residual modeling and context-based coding of the residuals. This algorithm assumes that prediction residuals follow a two-sided geometric distribution (TSGD). It then adopts Golomb-like codes, which are known to be approximately optimal for geometric distributions [5]. Compression for JPEG-LS is generally much faster than JPEG 2000 and much better than the original lossless JPEG standard [12].

4. Study of performance of lossless compression of HDR images

HDR image *memorial* in Fig. 3 is used as the primary example in this section.

4.1. Lossless compression of HDR image in RGBE format

Fig. 4 shows grayscale images of *R*, *G*, *B* mantissas and exponent *E*, and color image of mantissas of *R*, *G* and *B*. In Fig. 4, pixels are found to exhibit a high degree of correlation with its neighboring pixels, so it is easily deduced that the occurrence of one pixel clearly increases the likeliness of encountering a similar valued pixel in the same neighborhood for these images. We expect that