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Learning to display high dynamic range images

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Abstract

In this paper, we present a learning-based image processing technique. We have developed a novel method to map high dynamic range scenes to low dynamic range images for display in standard (low dynamic range) reproduction media. We formulate the problem as a quantization process and employ an adaptive conscience learning strategy to ensure that the mapped low dynamic range displays not only faithfully reproduce the visual features of the original scenes, but also make full use of the available display levels. This is achieved by the use of a competitive learning neural network that employs a frequency sensitive competitive learning mechanism to adaptively design the quantizer. By optimizing an L_2 distortion function, we ensure that the mapped low dynamic images preserve the visual characteristics of the original scenes. By incorporating a frequency sensitive competitive mechanism, we facilitate the full utilization of the limited displayable levels. We have developed a deterministic and practicable learning procedure which uses a single variable to control the display result. We give a detailed description of the implementation procedure of the new learning-based high dynamic range compression method and present experimental results to demonstrate the effectiveness of the method in displaying a variety of high dynamic range scenes.

Keywords: Learning-based image processing; Quantization; High dynamic range imaging; Dynamic range compression; Neural network; Competitive learning

1. Introduction

With the rapid advancement in electronic imaging and computer graphics technologies, there have been increasing interests in high dynamic range (HDR) imaging, see e.g., Ref. [1–17]. Fig. 1 shows a scenario where HDR imaging technology will be useful to photograph the scene. This is an indoor scene of very HDR. In order to make features in the dark areas visible, longer exposure had to be used, but this rendered the bright area saturated. On the other hand, using shorter exposure made features in the bright areas visible, but this obscured features in the dark areas. In order to make all features, both in the dark and bright areas simultaneously visible in a single image, we can create a HDR radiance map [3,4] for the scene. Using the technology of Ref. [3], it is relatively easy to create HDR maps for high dynamic scenes. All one needs is a sequence of low dynamic range (LDR) photos of the scene taken with different exposure intervals. Fig. 2 shows the LDR display of the scene in Fig. 1 mapped from its HDR radiance map, which has been created using the method of [3] from the photos in Fig. 1. It is seen that all areas in this image are now clearly visible. HDR imaging technology has also been recently extended to video [13,14].

Although we can create HDR numerical radiance maps for high dynamic scenes such as those like Fig. 1, reproduction devices, such as video monitors or printers, normally have much lower dynamic range than the radiance map (or equivalently the real world scenes). One of the key technical issues in HDR imaging is how to map HDR scene data to LDR display values in such a way that the visual impressions and feature details of the original real physical scenes are faithfully reproduced.

In the literature, e.g., Refs. [5–17], there are two broad categories of dynamic range compression techniques for the display of HDR images in LDR devices [12]. The tone reproduction operator (TRO) based methods involve (multi-resolution) spatial processing and mappings not only take into account the

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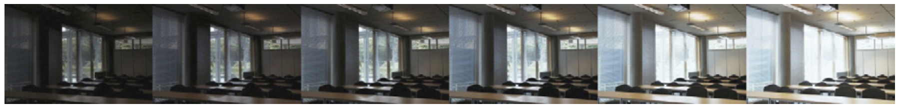

Fig. 1. Low dynamic range photos of an indoor scene taken under different exposure intervals.

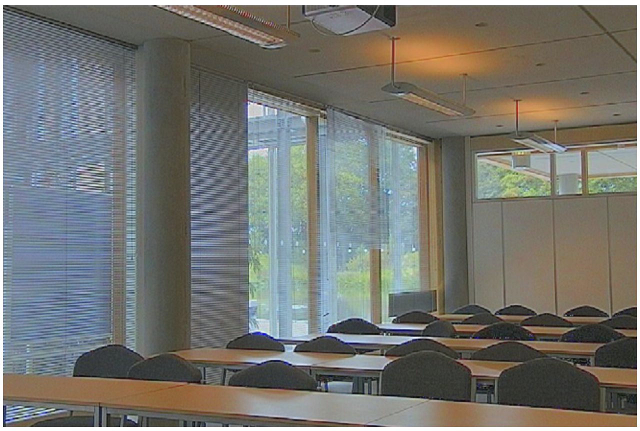

Fig. 2. Low dynamic display of high dynamic range map created from the photos in Fig. 1. The dynamic range of the radiance map is 488,582:1. HDR radiance map synthesis using Paul Debevec's HDRShop software (http://gl.ict.usc.edu/HDRShop/). Note: the visual artifacts appear in those blinds of the glass doors were actually in the original image data and not caused by the algorithm.

values of individual pixel but are also influenced by the pixel spatial contexts. Another type of approaches is tone reproduction curve (TRC) based. These approaches mainly involve the adjustment of the histograms and spatial context of individual pixel is not used in the mapping. The advantages of TRO-based methods are that they generally produce sharper images when the scenes contain many detailed features. The problems with these approaches are that spatial processing can be computationally expensive, and there are in general many parameters controlling the behaviors of the operators. Sometimes these techniques could introduce "halo" artifacts and sometimes they can introduce too much (artificial) detail. TRC-based methods are computationally simple. They preserve the correct brightness order and therefore are free from halo artifacts. These methods generally have fewer parameters and therefore are easier to use. The drawbacks of this type of methods are that spatial sharpness could be lost.

Perhaps one of the best known TRC-based methods is that of Ward and co-workers' [5]. The complete operator of Ref. [5] also included sophisticated models that exploit the limitations of human visual system. According to Ref. [5], if one just wanted to produce a good and natural-looking display for an HDR scene without regard to how well a human observer would be able to see in a real environment, histogram adjustment may provide an "optimal" solution. Although the histogram adjustment technique of Ref. [5] is quite effective, it also has drawbacks. The method only caps the display contrast (mapped by histogram equalization) when it exceeds that of the original scene. This means that if a scene has too low contrast, the technique will do nothing. Moreover, in sparsely populated intensity intervals, dynamic range compression is achieved by a histogram equalization technique. This means that some sparse intensity intervals that span a wide intensity range will be compressed too aggressively. As a result, features that are visible in the original scenes would be lost in the display. This unsatisfactory aspect of this algorithm is clearly illustrated in Figs. 9–11.

In this paper, we also study TRC-based methods for the display of HDR images. We present a learning-based method to map HDR scenes to low dynamic images to be displayed in LDR devices. We use an adaptive learning algorithm with a "conscience" mechanism to ensure that, the mapping not only takes into account the relative brightness of the HDR pixel values, i.e., to be faithful to the original data, but also favors the full utilization of all available display values, i.e., to ensure the mapped low dynamic images to have good visual contrast. The organization of the paper is as follows. In the next section, we cast the HDR image dynamic range compression problem in an adaptive quantization framework. In Section 3, we present a solution to HDR image dynamic range compression based on adaptive learning. In Section 4, we present detailed implementation procedures of our method. Section 4.1 presents results and Section 4.2 concludes our presentation and briefly discusses future work.

2. Quantization for dynamic range compression

The process of displaying HDR image is in fact a quantization and mapping process as illustrated in Fig. 3. Because there are too many (discrete) values in the high dynamic scene, we have to reduce the number of possible values, this is a quantization process. The difficulty faced in this stage is how to decide which values should be grouped together to take the same value in the low dynamic display. After quantization, all values that will be put into the same group can be annotated by the group's index. Displaying the original scene in a LDR is simply to represent each group's index by an appropriate display intensity level. In this paper, we mainly concerned ourselves with the first stage, i.e., to develop a method to best group HDR values.

Quantization, also known as clustering, is a well-studied subject in signal processing and neural network literature. Well-known techniques such as k-means and various neural network-based methods have been extensively researched [18–21]. Let $x(k)$, $k = 1, 2, \ldots$, be the intensities of the luminance component of the HDR image (like many other techniques, we only work on the luminance and in logarithm space, also, we treat