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Reproduction of HDR image on paper medium using Inkjet Printer

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Abstract

Display is the main low dynamic range media to represent HDR image. A lot of tone information and detail information can't be perceived when we use the conventional paper medium to reproduce HDR image because of the disadvantages of low dynamic range and small gamut of paper medium. However, Inkjet printing which is taken as the advanced and new method to reproduce the image has several advantages of larger gamut, higher dynamic as opposed to conventional printing. Inkjet printing was used to reproduce HDR image in view of the advantages in this paper. The process and characteristics of HDR image represented on paper medium using inkjet printing technique were studied. The tone properties of HDR image and inkjet printing paper were studied and the correlated curves were plotted to show the properties. We took several HDR images as the original images. Inkjet printing was the main method to present HDR image in this study. We developed two digital workflows using Cannon iPF8410s inkjet printer and HP Z6200 inkjet printer. And the color management was also used to guarantee the reproduction quality of digital printing process. The tone of HDR image was partitioned into three parts according to the human vision perception mechanism. The tone of paper medium was got from the process of digital printing workflow. The tone of paper medium was compared with the several tone partitioned from the HDR image. And the compared results were used to build the correlation between the HDR image tone and paper medium tone. Finally a multi-level tone partition system with correlated gamut methods was developed. The mechanism and method developed would help to solve the problems existing methods. The theory and technique foundation will also be promoted in such thesis.

Introduction

The range of HDR image is wider and more detailed information can be included. HDR image can be captured from real scenes or rendered using 3D computer graphics techniques. It can record more light information of real scenes than the LDR medium can do, i.e., display and paper medium. The information recorded in HDR image can't be displayed directly only using linear decoder technique and visual illusion often caused in the process of HDR image displaying process.

The tone range of paper medium is expanded with the help of development of digital printing technique including new material of substrate and ink. More detailed information can be recorded using digital printing technique. However, the LDR medium range is always set from 0 to 100 which is dependent on the properties of digital printing. Dot is the basic element to reproduce the tone in the printing process. Dot area is always from 0% to 100%. The tone range of HDR image is more wider than that of paper medium. Therefore it is necessary to use tone mapping technique to map the tone range of HDR image to the range of LDR medium. Edge preserve technique was also used in this paper to protect the detailed information and perception effect.

Tone mapping technique is often used to display the HDR image. Tone range is compressed to fit into the paper medium range while preserving detail. Tone range of HDR image should be compressed according to human visual system and the image properties to fit into the paper medium under the condition of equipments and medium in the HDR image representation using printing technique. And the level and detail information should be preserved to help get the authenticity of visual perception.

Tone mapping techniques used in such process were classified into two main methods. One is based on image formation mechanism and the other is based on the operation in the spatial domain. [1] However, none of the methods can deal with the HDR images individually. Computational complexity, represent or absence of artifacts should be considered to help getting the better visual perception. The differences between tone ranges of HDR images and paper medium were compared. And a model of multi-level tone partition system with correlated gamut methods was developed according to visual perception system and tone mapping technique. Finally, inkjet printer was used to represent the HDR images on the paper according to tone mapping technique and digital image processing technique.

Mechanism of Tone Mapping

Tone range value can be defined as the ration of maximum lightness and minimum lightness as follows in equation (1).

$$T = \frac{I_{max}}{I_{min}} \quad (1)$$

In which, I_{max} is the maximum lightness while I_{min} is the minimum lightness.

The difference between high dynamic range and low dynamic range can be shown in Figure 1. The high dynamic range covers a wider range of lightness while the low dynamic range only covers a narrower range of lightness.

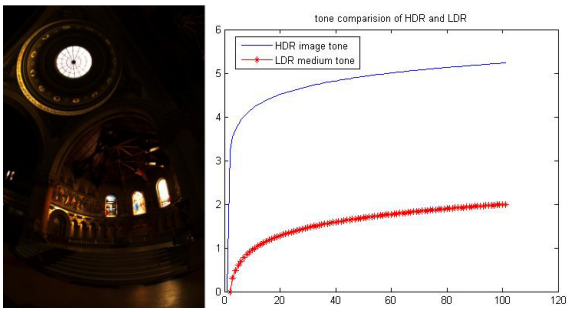
Figure 1 *Tone range comparison between HDR and LDR*

The dynamic range can be described in equation 2 according to human vision response rules as follows:

$$DynamicRange = log(\frac{MaxIntensity}{MinIntensity}) \quad (2)$$

In which, *DynamicRange* is the dynamic tone value of Image, *MaxIntensity* is the maximum tone value and *MinIntensity* is the minimum tone value.

So we can get the tone range curve of HDR image using the equation (2). It can be shown in Figure 2.



A B

Figure 2 *Tone range curves of HDR Image and paper medium. A: Original HDR Image B: Tone range curves*

According equation (1) and (2), the tone range of HDR image and LDR medium can be described as in equation (3).

$$\begin{cases} T_{LDR} = log(I_{LDR} + eps) \\ T_{HDR} = log(I_{HDR} + eps) \end{cases} \quad (3)$$

The T_{HDR} is compressed to fit into the T_{LDR} while preserving detail of HDR image, as followed in equation (4).

$$\Delta T = T_{HDR} - T_{LDR} = log(I_{HDR} + eps) - log(I_{LDR} + eps) = log\left(\frac{I_{HDR}+eps}{I_{LDR}+eps}\right) \quad (4)$$

However, it is too large for the difference between the dynamic ranges of HDR image and LDR medium to make ΔT tend to 0. The alternative choice is to make the ΔT optimal. Several mapping operators including global compression and local compression would be used in tone mapping methods. [2] Shadow area, light area and the common medium light area of tone range were obtained according the properties of HDR image and LDR medium. Local compression operator was used to map the tone of shadow area and light area while global compression operator was used to map the tone of common medium light area in this paper.

HDR Image Process

It is assumed that image is formed by light being reflected from surface of medium or scenes according to Retinex theory.[3] The image can be decomposed into two layers including lightness layer and detail layer, i.e., base layer and reflectance layer. It can be showed as follows:

$$R=I/L \quad (5)$$

In which, R is the reflectance, I is image pixel, L is the lightness. Logarithmic function is used to describe the relation between visual perception and lightness according the human visual system. It is showed as follows:

$$LogR = log(I/L) = logI - logL \quad (6)$$

Where, if we set $Detail=LogR$, $Image = LogI$, $Base = LogL$, we would get the following equation as follows:

$$\begin{cases} Detail = Image - Base \\ Image = Detail + Base \end{cases} \quad (7)$$

According to equation (7) the image can be decomposed into two parts or layers, detail layer and base layer. Tone mapping operator is only used in base layer while the detail layer is not processed. Bilateral filter is a better operator to process the HDR image to get the two layers. The processed images were as follows:

A B C

Figure 3 *Image processed by bilateral filter: A-original image, B-base layer, C-detail layer*

Bilateral filter has better layered effect for HDR image processing. The operator is easier to implement and has higher algorithm efficiency [4-5]. The process can be described as follows:

$$F(I(i,j)) = \sum W_{BF} * I(i,j) \quad (8)$$

Where,

$$W_{BF} = \frac{d(x_i,x_j)r(p_i,p_j)}{\sum_{j\in I(i,j)} d(x_i,x_j)r(p_i,p_j)}, \; d(x_i,x_j) = -\frac{1}{2\pi\delta_d}\exp\left(\left(\frac{\|x_i-x_j\|}{\delta_d}\right)^2\right),$$

$$r(p_i,p_j) = -\frac{1}{2\pi\delta_r}\exp\left(\left(\frac{\Delta E_{ab}(p^i,p^j)}{\delta_r}\right)^2\right).$$

BF is to use bilateral filter. I_{in} is original image, $d(x_i,x_j)$ is the Gaussian function of the distance between pixel i and pixel j, $r(p_i,p_j)$ is the Gaussian function of the color difference between pixel i and pixel j. δ_d is to represent the spatial position relation between pixel i and pixel j. δ_r is to represent the color difference relation between pixel i and pixel j.

Perception of detail is affected by lightness according to human visual theory. More detail information can be perceived when lightness increases. On the other hand less detail can be perceived when lightness decreases. [6] Consequently, perception of detail is affected by the lightness when implementing tone compression. Several operators were applied in the detail layer to preserve the detail information in this paper. The process was shown in equation (9).

$$D_{out} = D_{in}^{\alpha} \quad (9)$$

Where, D_{in} is detail information of HDR image. D_{out} is compensated using parameter α. α is as follows:

$$\alpha = \begin{cases} a > 1, L \in L_{range}, \; \Delta L < 0 \\ 0 < b < 1, L \in L_{range}, \; \Delta L > 0 \\ 1, others \end{cases} \quad (10)$$

Where, L_{range} is the range of human visual perception. ΔL is the lightness difference between mapped tone and original tone. Perception of detail changes with lightness for $L \in L_{range}$. Consequently, detail layer should be compensated to keep perception consistency when $\Delta L < 0$. Detailed layer should be compressed to eliminate false contouring and haloes

caused by excessive enhancement when $\Delta L > 0$. When lightness changes exceed the limits of visual perception the capability to perceive more detail goes down no matter how lightness changes.

Experiment and discussion

Two digital workflows using Cannon iPF8410s inkjet printer and HP Z6200 inkjet printer were developed to get the tone range of paper medium. And the color management was also used to guarantee the reproduction quality of digital printing process. The tones of original HDR images were partitioned into three parts according to mechanism discussed in the above sections. The tone of paper medium was compared with the several tone partitioned from the HDR image. And the compared results were used to build the correlation between the HDR image tone and paper medium tone. Original HDR images were shown in Figure 4. The tones of HDR images and LDR medium were obtained and compared in Figure 5.

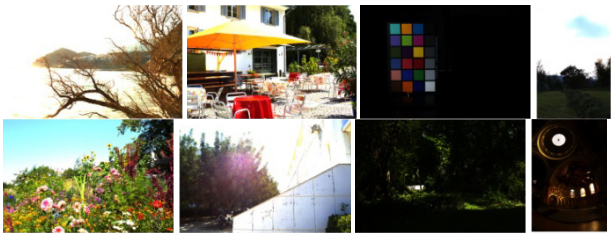


Figure 4 *Original HDR Images*

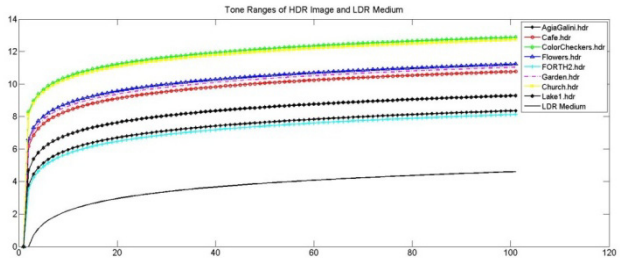


Figure 5 *tones of HDR images and LDR medium*

In the bilateral filter processing for original image, δ_d was set as 2.54 and δ_r was set as 3. In the process of compensation for detail layer, *a* was set as 1.5 and *b* was set as 0.8 for the common medium light area of tone range. In shadow area and lighter area of the tone, α was set as 1. The HDR images were outputted on paper medium after processed. The basic impression of the outputted HDR images was shown in Figure 6.

Figure 6 *Images represented on paper medium*

From Figure 4 and Figure 6, more detail information of the HDR images was perceived. The differences between the original HDR images and the outputted images on paper medium were very obvious.

Summary

Two digital workflows using Cannon iPF8410s inkjet printer and HP Z6200 inkjet printer were developed to output the HDR images and mapped HDR images. And the color management was also used to guarantee the reproduction quality of digital printing process. The tone of HDR image was partitioned into three parts according to the human vision perception mechanism. The tone of paper medium was got from the process of digital printing workflow. The tone of paper medium was compared with the several tone partitioned from the HDR image. And the compared results were used to build the correlation between the HDR image tone and paper medium tone. The tone range was partitioned into three parts. Each portioned tone was mapped using different parameter to solve the problems existing methods. The theory and technique foundation will also be promoted in such thesis.

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Author Biography

Xiaozhou Li received his BS in printing engineering from Shandong Institute of Light Industry (2004) and his PhD in pulp and paper engineering from South China University of Technology (2012). Since then he has worked in the Printing and Packaging Engineering at Qilu University of Technology in Jinan, China. His work has focused on the Color Science and Technology.