

A Simple Tone Mapping for High Dynamic Range Image Visualization Using a Pseudo-Hilbert Scan

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Abstract

The Hilbert curve is one of space-filling curves published by G. Peano. There are several applications using this curve, such as image processing, computer graphics, etc. In this paper, we concentrate on a tone mapping technique for high dynamic range images using the Pseudo-Hilbert curve. Based on the neighbourhood property of the Pseudo-Hilbert scan, a fast and flexible tone reproduction method is proposed. The proposed new technique preserves visibility and contrast impression of high dynamic range scenes in low dynamic range reproduction devices. From the experimental results, we have confirmed that the proposed method produces good results on a variety of high dynamic range images.

1. Introduction

The Hilbert curve is a one-to-one mapping between N -dimensional (N -D) space and one-dimensional (1-D) space, which preserves point neighbourhoods as much as possible. There are several applications, such as image processing, pattern recognition, computer graphics, etc. A historical review of Hilbert curve applications can be seen in [1]. And Figure 1 shows three Hilbert curves with different resolutions. However, in fact, the size of an image may be arbitrary. So generally a two-dimensional Pseudo-Hilbert scan is used [2]. The Pseudo-Hilbert scan is also a one-to-one mapping between 2-D space and 1-D space, which preserves some special spacial property of the 2-D datum. Figure 2 shows two different Pseudo-Hilbert curves.

The high dynamic range (HDR) images record the full dynamic range of the scene in the real world. However, most current output devices, such as computer monitors and printers, often only enables a part of the scene visible, which is much lower than the dynamic range of the scene. So the question is then how we can reproduce or render such images in a standard output device? In order to solve this question, mapping or tone reproduction technique is used to map HDR values to LDR values.

Currently, there has been a lot of research done for the tone mapping problem. And a number of mapping algorithms have been proposed. According to their own properties, they usually can be categorized into two main groups, i.e., tone reproduction curve (TRC) based [3,4] and tone reproduction operator (TRO) based [5,6]. TRC consists of the algorithms that map the original range to

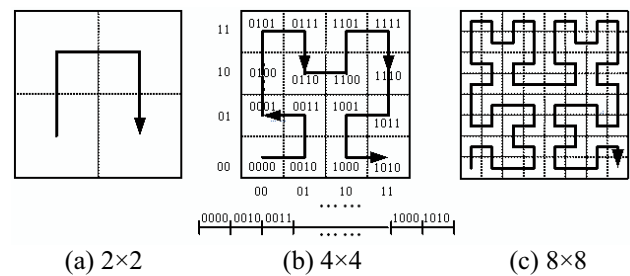


Figure 1. Hilbert scan.

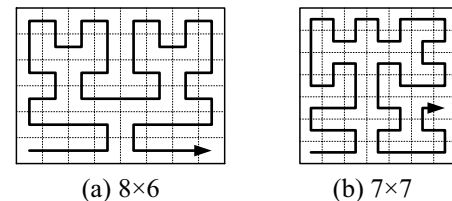


Figure 2. Pseudo-Hilbert scan

he output range in accordance with the pixel distributions. These algorithms can preserve the subjective perception of the scene. However, simple global processing will cause a loss of contrast, which is apparent in the loss of detail visibility.

TRO refers to the algorithms which use a local processing for reproduction. Local processing based on the Retinex theory [7] can increase the local contrast, which improves the visibility of some parts of the image. But it may also cause “halo” effects in the reproduction. Moreover, TRO methods usually have many parameters for the users to set, which makes them difficult to use. Compared with TRC methods, TRO methods have a much higher computational complexity because they involve a local special processing.

In this paper, a simple tone reproduction algorithm based on the Pseudo-Hilbert scan is proposed. Our method belongs to the TRC category. Before the reproduction, we use the Pseudo-Hilbert scan to map the luminance of a 2-D image into 1-D indexes. Then utilizing the neighbourhood property of the Pseudo-Hilbert scan, we divided the image into an array of blocks and detected the edges, which prevents the histogram from being dominated by large and uniform color areas. Finally, based on the average luminance value of each block, we use the histogram adjustment technique to allocate dynamic range in proportion to the pixels distribution. The proposed approach has been implemented and tested in an image database. The experimental result shows that this algorithm is effective and easy to use, only one parameter need setting.

2. Hilbert and Pseudo-Hilbert Scan

In 1891, D. Hilbert found a one-to-one mapping between segments on the line and quadrants on the square, which was called the Hilbert curve. It is one of the space-filling curves. Since then, there are a lot of papers of Hilbert curves published by many mathematicians. And the computation methods of this curve are proposed by several researchers. Among them, the address alignment based on two look-up tables [9] has low computational complexity and requires little memory, so it is used widely in different research areas.

Hilbert scan has a merit that a clustering is much easier than other scanning method. It is demonstrated that the subsquares can be arranged so that the inclusion relationships are preserved, that is, if a square corresponds to an interval, then its subsquares correspond to subintervals of that interval. Figure 1 (b) describes how this process is to be carried out. Thus the Hilbert scan can preserve neighborhoods points as much as possible

Although the Hilbert scan has so many attractive properties, it is very difficult to be put in practice because of its restriction. It requires the scanned region must be a square and the length of each side must equal the power of two, which is very difficult to satisfy in implementation. The Pseudo-Hilbert scan is an extension of the Hilbert scan [2]. This scan technique can be used for an arbitrarily-sized rectangle. Furthermore, due to the Pseudo-Hilbert scan complies with the Hilbert scan in global sense, it still holds the property that the scanning curve preserves high correlation of the original 2-D data. Comparing between Figure 1 and 2, we can also find that these two scans have many similarities.

3. The Reproduction Algorithm

In this section, we propose a TRC-based algorithm based on the Pseudo-Hilbert scan. It can overcome the problems mentioned above while achieving satisfactory results. The algorithm includes three steps. First, like other reproduction techniques, we use a global mapping to compress the dynamic range and let the output adjust to the display luminance of the output devices. Second, based on the Pseudo-Hilbert transformation, the edges of an image are detected in accordance with the average luminance value of the blocks. At last, we create the TRC by equalizing luminance histogram.

3.1. Global Luminance Mapping

Our work is totally focused on the luminance channel and all the operations are performed in logarithm space. So we firstly compute the luminance L (in cd/m²) from the RGB space. In the LHS (luminance, hue, and saturation) system, the luminance is defined as

$$L = 0.299R + 0.587G + 0.114B \quad (1)$$

Then, we assume the logarithmic relation in our tone mapping solution following Ref. [4] which recommends such a relation for image processing purposes:

$$L_d = \frac{\log(L_w + \varphi) - \log(L_{\min} + \varphi)}{\log(L_{\max} + \varphi) - \log(L_{\min} + \varphi)} \quad (2)$$

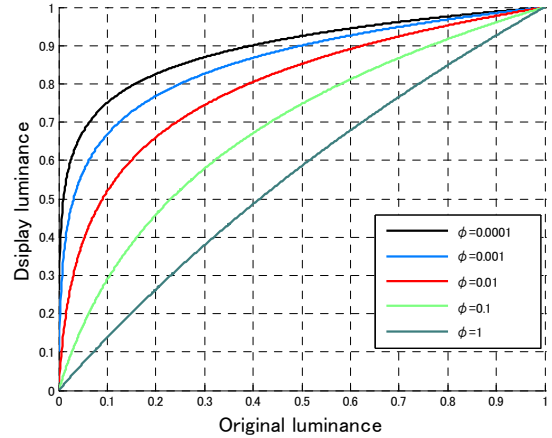


Figure 3. The global luminance mapping curve under different values of φ .

where L_{\max} and L_{\min} are the maximum and minimum luminance of the scene, and $\varphi = \beta(L_{\max} - L_{\min})$, $\beta \geq 0$. And for each pixel, the displayed luminance L_d is obtained from the ratio of world luminance L_w and L_{\max} . This mapping is a one-to-one mapping, and ensures that the maximum luminance value of the scene is mapped to one (white) and other luminance values are smoothly decreased. Adjusting β can control the overall brightness of the reproduced image. For example, when β decreases, the display will be bright and this leads to increase the sensitivity for dark areas. Figure 3 shows the mapping curve of Equation (1) for different φ , where we assume that the range of original luminance is limited from 0 to 1.

3.2. Edge Detection Based on the Pseudo-Hilbert Scan

Scanning each component of a luminance image with the resolution $X \times Y$ along the a Pseudo-Hilbert curve, then we obtain an one-dimensional data by the following equation,

$$D_i = f(L_d(x, y)). \quad (3)$$

Where an order tern (x, y) of integers x and y is the coordinates of a pixel, $0 \leq x < X$ and $0 \leq y < Y$. The symbol D_i represents the i th display luminance value in the one-dimensional data, $0 \leq i < X \cdot Y$.

The edge detection is based on a simple segmentation technique of these 1-D data. Firstly, we divide the scanned data into p blocks with fixed length,

$$\underbrace{(D_0, D_1, D_2, \dots, D_7)}_{S_0} \cdots \underbrace{(D_{8k}, \dots, D_{8k+7})}_{S_k} \cdots \underbrace{(D_{8p}, \dots, D_{8p+7})}_{S_p}$$

For each block s_j ($0 \leq s_j \leq p$), compute the average luminance,

$$\widetilde{D}_{S_k} = \frac{D_{8k} + \dots + D_{8k+7}}{8}. \quad (4)$$

Then in order to assign larger dynamic range for highly populated regions, the contrast of more image textures and details should be expanded. While edge detection can extract object boundary information and prevent the

statistical histograms from being dominated by larger areas of uniform luminance. Therefore in this study, we designed an edge detection method which includes two steps. At first, we calculate the luminance deviation index C_{S_k} of each block by the following equation

$$C_{S_k} = \frac{|\widetilde{D}_{S_k} - \widetilde{D}_{S_{k+1}}|}{\widetilde{D}_{S_k} + \widetilde{D}_{S_{k+1}}} \quad (5)$$

Finally for each block, we set a boundary flag F_{S_k} by

$$F_{S_k} = \begin{cases} 1 & C_{S_k} \geq \psi \\ 0 & C_{S_k} < \psi \end{cases} \quad (6)$$

where ψ is a predefined threshold value, which is set as 0.37 in this study. When the flag of a block equals one, this block is called edge.

3.3. Histogram Adjustment

The reproduced luminance values are in the range $[0,1]$, so the average luminance of each block is also in the range of 0 to 1. Assuming these luminance values of the edges has a high resolution histogram (in the order of 100,000 bins), the output image still contains the very high dynamic range information even ignoring numerical errors. Thus, a quantization processing is required. In order to preserve details and contrast of the original image, the pixel distribution should be taken into account in the quantization. The traditional histogram equalization divides the original range into $N (=100)$ intervals based on the pixel distribution. Within each interval, there is equal number of pixels falling onto it. And pixels falling into the same interval are quantized into the same luminance. The following function shows how we divide the high dynamic range based on the luminance value of edges.

$$\int_{\tilde{D}_{\min}^{e_k}}^{e_k} h(x)dx = \frac{k}{N} \int_{\tilde{D}_{\min}}^{\tilde{D}_{\max}} h(x)dx, \quad k = 1, \dots, N-1 \quad (7)$$

where $h(x)$ is the histogram, \tilde{D}_{\min} and \tilde{D}_{\max} are the minimum and maximum values of the edges, and e_k is the cutting value which divides the range into N intervals. The luminance values in the range $(e_k, e_{k+1}]$ are mapped (quantized) into a same value.

4. Experimental Results

In our simulation, we compute the HDR luminance signal by Equation (1) firstly. Then the HDR luminance is mapped into the display luminance by the global compression function (2). Thirdly, based the Pseudo-Hilbert scan, we transform the 2-D luminance image into a 1-D array of luminance and detect the edge in accordance with the average luminance value of each block. Fourthly, the histogram adjustment technique of section 3.3 is used to adjust the luminance values of all the edges to display luminance. Finally, the LDR image is rendered.

From RGB space to the LHS or YIQ system, the luminance component has the same transformation form described in Equation (1). The scaling and shifting can be

applied to the luminance processing applications [8]. Their purposes are to change the luminance to the desired value without changing the color. However, scaling and shifting will produce final images with different saturations in accordance with different systems. Moreover, the change in luminance can be large for histogram equalization when most of the pixels of the original image have low or high luminance. For images with a histogram that is almost uniformly distributed, the difference between the performance of scaling and shifting is not very perceptible. However, for bright or dark images, the differences are quite obvious. So in order to combine these two techniques and find a good tradeoff between them, we construct the following objective function to compute the output RGB values of LDR pixels,

$$\begin{cases} R_{out} = \gamma R_{in} \cdot \frac{L_{out}}{L_{in}} + (1-\gamma) \cdot (R_{in} + L_{out} - L_{in}) \\ G_{out} = \gamma G_{in} \cdot \frac{L_{out}}{L_{in}} + (1-\gamma) \cdot (G_{in} + L_{out} - L_{in}), 0 < \gamma \leq 1. \\ B_{out} = \gamma B_{in} \cdot \frac{L_{out}}{L_{in}} + (1-\gamma) \cdot (B_{in} + L_{out} - L_{in}) \end{cases} \quad (8)$$

In the above equation, L_{in} and L_{out} represent the original and output luminance values respectively, and the parameter γ is used to control the display color.

Figure 4 shows four examples of mapped HDR images. From the figure 4(a), we can see that the gamma-encoded image loses much information about luminance and makes the whole image very dark, while the proposed method can increase the visibility of local details. Figure 4(b)-(e) show other cases of HDRI mapping, and subjective comparisons of them indicate that the proposed algorithm is effective and performs well.

5. Conclusions

In this paper, a new reproduction method is proposed for rendering the HDR images. The proposed mapping algorithm based on the Pseudo-Hilbert scan utilizes a simple local processing (Section 3.2 and 3.3), which is helpful to increase the visibility of local details in the LDR image. The experimental results have demonstrated the effectiveness of the new method.

References

- [1] H. Sagan: "Space-filling Curve," *Springer Verlag*, 1999.
- [2] J. Zhang, S. Kamata, and Y. Ueshige: "A Pseudo-Hilbert Scan Algorithm for Arbitrarily-Sized Rectangle Region", *Proceedings of International Workshop on Intelligent Computing in Pattern Analysis/Synthesis*, vol.4153, pp.290-299, 2006.
- [3] G. W. Larson, H. Rushmeier, and C. Piatko: "A visibility matching tone reproduction operator for high dynamic range scenes," *IEEE Trans. Visual. Comput. Graph.*, vol.3, pp.291-306, 1997.
- [4] J. Duan and G. Qiu: "Fast Tone Mapping for High Dynamic Range Images," *ICPR '04*, vol.2, pp.847-850, 2004.
- [5] A. Pardo and G. Sapiro: "Visualization of High

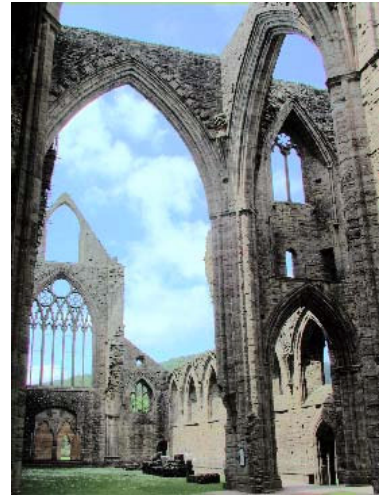
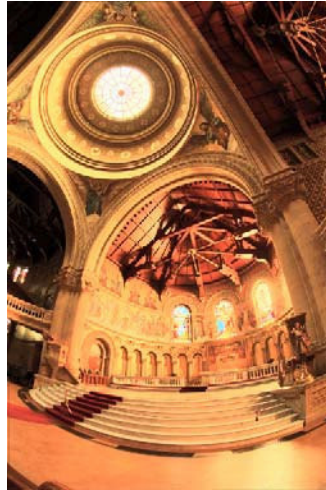
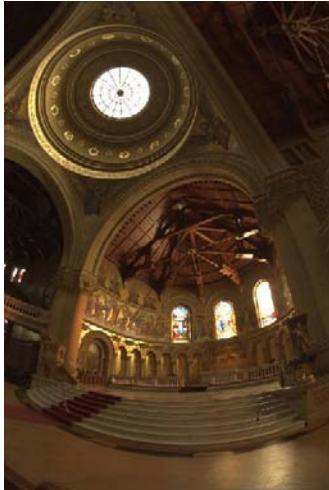
Dynamic Range Images,” *IEEE Trans. Image Processing*, vol.12, no.6, pp.639-647, 2003.

[6] L. Meylan and S. Susstrunk: “High Dynamic Range Image Rendering With a Retinex-Based Adaptive Filter,” *IEEE Trans. Image Processing*, vol.15, no.9, pp.2820-1830, 2006.

[7] E. Land: “The Retinex,” *Amer. Scient.*, vol.52, no.2, pp.247-264, 1964.

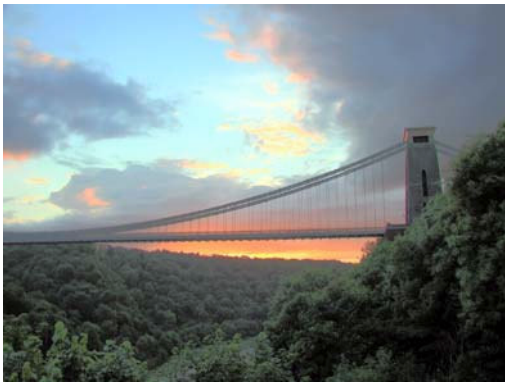
[8] C. Yang and J. Rodriguez: “Efficient Luminance and Saturation Processing Techniques for Bypassing Color Coordinate Transformations,” *Proc. IEEE Int’l Conf. on Systems, Man, and Cybernetics*, vol.1, 1995.

[9] S. Kamata, R. Eason and Y. Bandou: “A New Algorithm for N-dimensional Hilbert Scanning,” *IEEE Trans. Image Processing*, vol.8, no.7, pp.964-973, 1999.



(a) Memorial Church. Left: Gamma-encoded image. Right: image treated with the proposed method

(b) Tintern



(c) Bristol



(d) Clockbui

Figure 4. Outputs of the proposed new HDR reproduction technique. (a) Memorial Church: $L_{\max} = 224.8$, $L_{\min} = 0.00066$, dynamic range: 340,016:1, $\gamma = 0.65$. (b) Tintern: $L_{\max} = 0.322$, $L_{\min} = 0.000609$, $\gamma = 0.65$. (c) Bristol: $L_{\max} = 0.951$, $L_{\min} = 0.0000983$, $\gamma = 0.65$. (d) Clockbui: $L_{\max} = 0.99$, $L_{\min} = 0.0000673$, $\gamma = 0.65$.