Highlight Removal Method for HDR Images

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Abstract

This paper presents a single-image highlight removal method for High Dynamic Range images based on histogram transformation (HiRemHDR). The approach exploits specific characteristics of highlight region found in HDR Images. Unlike with LDR Images, color clipping never occurs in HDR highlight area. Each pixel of this area carry color information which is a direct sum of diffuse and specular component. This fact enables us to use a simple method of histogram transformation with satisfying results. Experimental image outcome is given to demonstrate the performance of the HiRemHDR. The approach can be used as a preprocessing step for many image processing algorithms, which require an input image to be without high luminance regions.

Keywords: Highlight Removal, High Dynamic Range Imaging, Histogram Equalization, Image Processing

1 Introduction

The terms High Dynamic Range (HDR) and High Dynamic Range Imaging (HDRI) are used whenever intensity values that span 4 or more orders of magnitude are acquired, stored or displayed. A High-Dynamic Range image is an image that has a greater dynamic range than can be shown on a standard display device, or that can be captured with a standard camera with just a single exposure. A related term Low Dynamic Range refers to digital systems supporting only 8 bits per color channel or intensity ratios below 300:1. Since the beginnings of photography we have learned to accept the limitations of the film medium and have carried these lowered expectations into the digital world as well.

The need for accurate reproduction of intensity and contrast in digital images is critically important for many applications. For example, in medical diagnostics or computed tomography, also MRI and other scanning technologies produce images with exceptionally high density ratios. Most computer vision applications can benefit from higher dynamic range in their input.

Although highlight has a common meaning of something important, it is not the case when it comes to highlights in images processing. These highlights denote area of an image with the highest value of luminance. A common limitation in digital image processing is the requirement for a scene to consist only of matte (Lambertian) surfaces. Surrounding environment also contains specular surfaces, which reduces the applicability of image processing methods. Specular areas appear as surface features, when in fact they are artifacts caused by lighting that change in position and appearance under different viewing conditions [7].

Highlight in digital images cause many problems, they can lead to false segmentation, stereo mismatch and recognition errors [7]. Often highlights are misinterpreted as light objects or light patterns on surfaces [6]. All these undesirable effects on image analysis are intact with HDR images. The emerging importance of HDR images and negative impact of highlights were our major motivation for developing a highlight removal method for HDR images.

Section 2 describes the present state of methods used in highlight removal area. In Section 3, we provide general description of HiRemHDR. Section 4 describes the method from the implementation perspective and examines the results of it. In Section 5, we present conclusion and indicate possible future work on our algorithm.

2 Previous Work

Given the importance of the highlight removal problem for image processing it is not a surprise to find quite many material on this subject.

Klinker et al. [1] introduced a single-image approach for highlight removal. He observes that the colors of all light rays reflected from one object form a planar cluster in the color space. The shape of this cluster is determined by the object and highlight colors and by the object shape and illumination geometry. He presents a method which exploits the difference between object color and highlight color to separate the color of every pixel into a matte component and a highlight component.

Schluns and Koschan [6] present in their paper two approaches to highlight removal in color images. The first approach is based on a global analysis of a single color image. The second approach is based on a local analysis of three color images.

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Ragheb and Hancock [5] consider how to subtract both types of highlight from shiny surfaces in order to improve the quality of surface normal information recoverable using shape-from-shading.

Tan et al. [7] proposes a single-image highlight removal method that incorporates illumination-based constraints into image inpainting. Constraints provided by observed pixel colors, highlight color analysis and illumination color uniformity are employed in their method to improve estimation of the underlying diffuse color. The inclusion of these illumination constraints allows for better recovery of shading and textures by inpainting.

However, all of the methods mentioned above focused on LDR images and did not utilize specific features of HDR images. This fact is a major motivation to pursue the subject. Although many of the previous techniques use the dichromatic reflection model, HiRemHDR focuses entirely on utilization of HDR features.

3 Description of Highlight Removal Method

Highlight removal has a special value for HDR images. It can be for example used for tone mapping as a preprocessing step. It determines the value of luminance which is perceived as white. Additionally, like with LDR images, it is useful for image analysis algorithms.

Now we focus on the proposed highlight removal method. As shown in figure 1, our algorithm uses HDR image (with highlight regions) as an input, then performs certain operations on this image resulting in an output image without highlights.

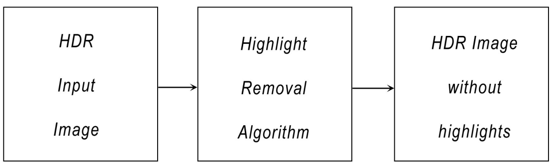


Figure 1: General view of HiRemHDR method

Let us delve into working details of the HiRemHDR method (i.e. the algorithm).

Steps of our algorithm can be described as follows:

- **step 1:** read HDR image into three separate channels X, Y and Z,
- **step 2:** convert XYZ color space to YUV,
- **step 3:** perform normalization for luminance channel Y,
- **step 4:** apply histogram equalization for channel Y,
- **step 5:** execute polynomial transformation for channel Y,

At first a HDR image is read and its values are put into X, Y and Z matrices, which represent three channels of an image (**step 1**). Then, a normalization of matrices X, Y and Z is performed which consist of subtracting the smallest value of X, Y and Z from all the values of the corresponding matrix (i.e. the smallest value of X is subtracted from all the values in this matrix and the same thing is done with Y and Z).

Step 2 involves color space conversion. Base XYZ color space is transformed to YUV, where Y is a luminance channel and U, V are chromaticy channels (equation 1). This step separates color luminance information from color chromaticy, which allows further processing.

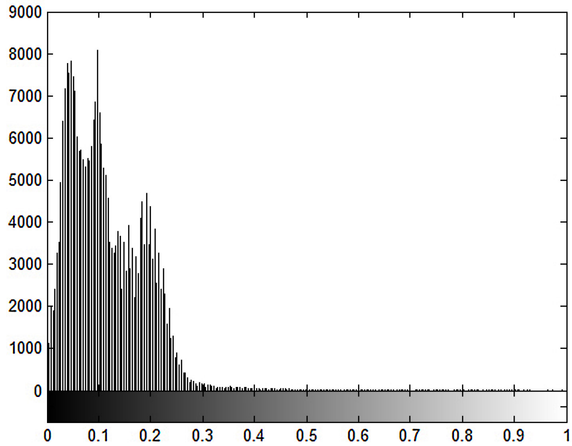
$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 * R + 0.587 * G + 0.114 * B \\ 0.492 * (B - Y) \\ 0.877 * (R - Y) \end{bmatrix} \tag{1}$$

After that, the lowest value of channel Y is mapped to 0 and the highest value to 1 (**step 3**). Normalization is a process of scaling the numbers in a data set. The main goal of it is to improve the accuracy of the subsequent numeric computations.

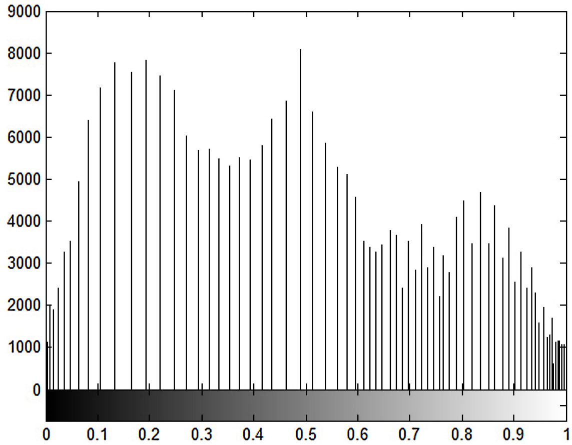
Step 4 applies histogram equalization for the luminance channel Y. Histogram equalization will not flatten a histogram. It redistributes intensity distributions, the original image is rescaled so that the histogram of the enhanced image follows some desired form [4]. If the histogram of an image has peaks and valleys, it will still have peaks and valley after equalization, but peaks and valley will be shifted [2]. The result of this operation is shown in Figure 2. A uniform histogram is required for the next step transformation to work properly.

Step 5 executes the intensity transformation for channel Y. Each value of the channel is replaced by the return of special *f(x)* function of this value (example: $x_{12} = f(x_{12})$. The function has been obtained by a 4^{th} degree polynomial approximation of certain experimentally acquired transformation points, as shown in figure 3. For each image exists the optimal luminance transformation curve, which removes high luminance highlight areas from that particular image. If we normalize luminance values and equalize its histogram it is possible to determine the single transformation curve, optimal for the most of HDR images. Coefficients of this curve have been determined by averaging optimal coefficients from HDR images in research series. Equation 3 and matrix of coefficients *P* show the actual polynomial used.

$$f(x) = p_0\, x^4 + p_1\, x^3 + p_2\, x^2 + p_3\, x + p_4 \tag{2}$$



(a)



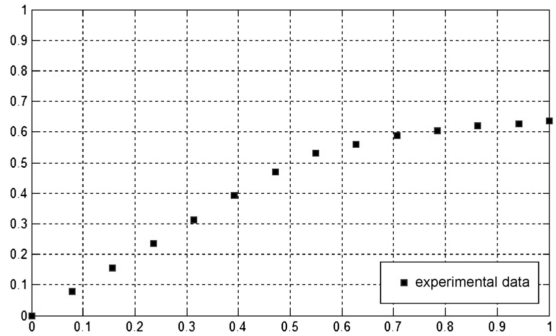
(b)

Figure 2: Results of the histogram equalization. Image histogram before histogram equalization (a). Image histogram after histogram equalization (b).

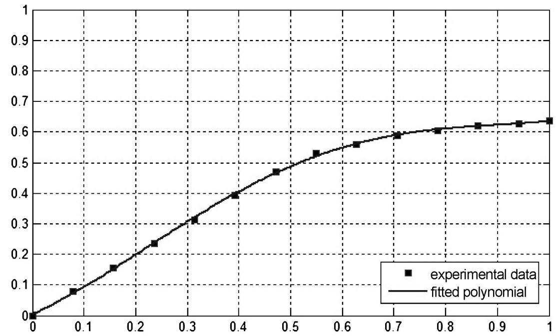
Where:

$$P = \begin{bmatrix} p_0 \\ p_1 \\ p_2 \\ p_3 \\ p_4 \end{bmatrix} = \begin{bmatrix} 1.54 \\ -3.426 \\ 1.773 \\ 0.7435 \\ 0.00436 \end{bmatrix} \tag{3}$$

The result of the transformation is shown in figure 4. It can be seen that after the transformation is applied, the values occupying the lightest areas of the histogram shift to the darker areas. By so doing, the highlight regions are removed. Matrices I and I' (equation 4 and 5) show selected area of the image luminance channel before and after polynomial transformation. Note that the precision has been reduced for the presentation purposes. Figure 5 presents the influence of the transformation on the selected



(a)



(b)

Figure 3: Polynomial approximation of experimentally acquired points. Experimentally acquired transformation points (a). Polynomial approximation of acquired points (b).

area of an image.

$$I = \begin{bmatrix} 0.99 & 0.98 & 1.00 & 0.97 & 0.97 & 0.45 & 0.23 \\ 1.00 & 0.98 & 0.98 & 1.00 & 0.99 & 0.55 & 0.28 \\ 0.98 & 1.00 & 0.99 & 0.97 & 1.00 & 0.73 & 0.28 \\ 1,00 & 0.98 & 0.99 & 1.00 & 0.96 & 0.58 & 0.23 \\ 0.99 & 0.96 & 0.99 & 0.99 & 0.80 & 0.38 & 0.18 \\ 0.71 & 0.82 & 0.91 & 0.80 & 0.56 & 0.25 & 0.15 \\ 0.57 & 0.57 & 0.63 & 0.58 & 0.40 & 0.21 & 0.13 \\ 0.35 & 0.41 & 0.48 & 0.41 & 0.28 & 0.18 & 0.12 \\ 0.28 & 0.30 & 0.35 & 0.29 & 0.23 & 0.15 & 0.09 \end{bmatrix} \tag{4}$$

$$I' = \begin{bmatrix} 0.62 & 0.61 & 0.63 & 0.60 & 0.60 & 0.45 & 0.23 \\ 0.63 & 0.61 & 0.61 & 0.63 & 0.62 & 0.52 & 0.29 \\ 0.61 & 0.63 & 0.62 & 0.60 & 0.63 & 0.60 & 0.29 \\ 0.63 & 0.62 & 0.62 & 0.63 & 0.62 & 0.54 & 0.23 \\ 0.62 & 0.61 & 0.62 & 0.62 & 0.61 & 0.38 & 0.18 \\ 0.59 & 0.61 & 0.62 & 0.61 & 0.53 & 0.25 & 0.15 \\ 0.53 & 0.53 & 0.56 & 0.54 & 0.40 & 0.21 & 0.12 \\ 0.36 & 0.42 & 0.47 & 0.41 & 0.29 & 0.18 & 0.11 \\ 0.29 & 0.31 & 0.36 & 0.30 & 0.23 & 0.14 & 0.09 \end{bmatrix} \tag{5}$$

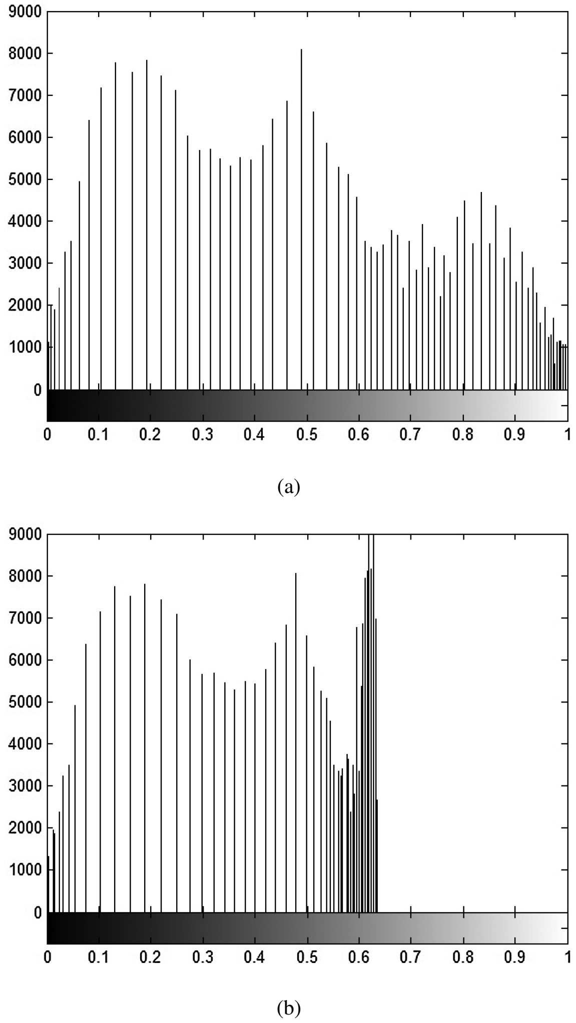


Figure 4: The effect of transformation on the image histogram. Histogram before transformation (a). Histogram after transformation (b).

4 Implementation and Results

The following section presents our method from the implementation perspective. The code is provided to illustrate the crucial part of our algorithm. The second part of the section shows the experimental results of highlight removal.

4.1 Implementation

Matlab 7 was employed as a research and implementation environment. HDR images from MCSL HDR image database were used for method testing purposes. They are encoded in the Radiance RGBE format (rle) [8] and to facilitate this format in Matlab, the Taplin's READ_RLE_RGBE function was utilized. The READ_RLE_RGBE function reads an HDR image and places its contents into a three dimensional matrix, each dimension representing single channel (X, Y and Z) of an image.

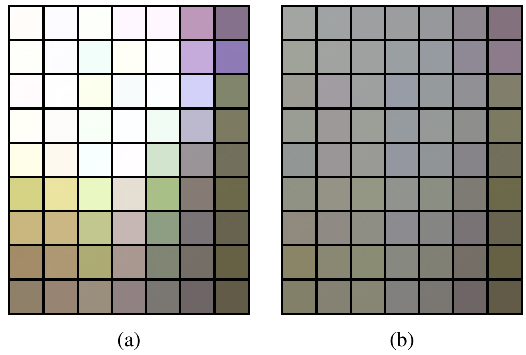


Figure 5: The effect of transformation on the selected area of an image. The selected area before transformation (a). The selected area after transformation (b).

Before further processing, the color space of an image is transformed from RGB to YUV.

Next, the normalization is performed on the luminance matrix. The operation is very common and does not require more detailed explanation than provided in section 3.

The following step involves a usage of the Matlab's Image Processing Toolbox HISTEQ function for histogram equalization.

After that, intensity transformation is executed which is presented in the pseudocode below::

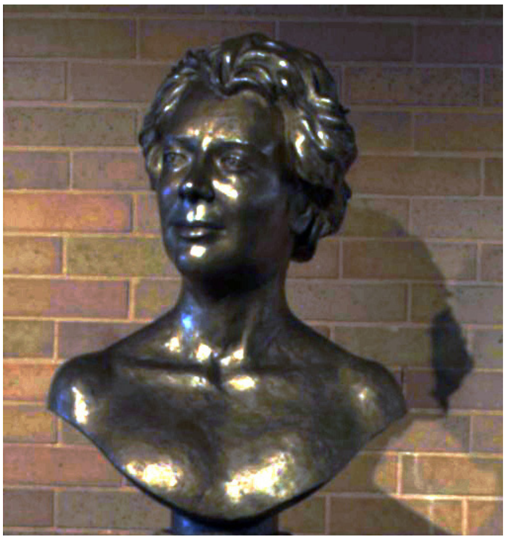
```
  //Function transforms the value using
polynomial //equation 1 from section 3
  FUNCTION PolyTrans (x)
    p1:=1.54;
    p2:=-3.426;
    p3:=1.773;
    p4:=0.7435;
    p5:=0.00436;
    y:=p1*x^4 + p2*x^3 + p3*x^2 + p4*x + p5;
    RETURN y
  END FUNCTION

  //Polynomial transformation is applied to the
//luminance matrix, i.e.  channelY(i,j)
  FUNCTION ImageTrans()
    FOR i:=1 TO ImageWidth DO
      FOR j:=1 TO ImageHeight DO
        channelY(i,j):=PolyTrans(channelX(i,j));
      END
    END
  END FUNCTION
```

Highlight regions are removed during the last step. In the next subsection we present the results of HiRemHDR.

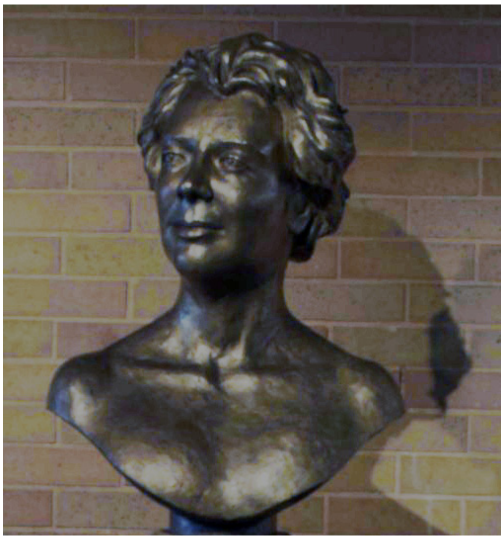
4.2 Results

As mentioned before, testing of HiRemHDR method was conducted on several HDR images from MCSL HDR image database [8]. The major goal of testing procedure was to proof that our approach successfully removes highlights from different kind of images. The first example, shown in figure 6, verifies the effectiveness of highlight removal.

As can be seen, highlights from the surface of the sculpture have disappeared.



(a)



(b)

Figure 6: Results of our highlight removal method. Image before highlight removal (a). Image with highlight removed by our algorithm (b).

However on some images not all of highlights are represented by the highest value of luminance. These images have other bright surfaces. In that case HiRemHDR method is only partially successful. Figure 7 illustrates this flaw. The highlight on the blue part of the racecar hood has low luminance, which is not reduced by the polynomial transformation. A possible solution of this problem might be the usage of our method locally, only on the part of image with a highlight which could not be removed globally. However, such approach would require a user interaction to mark the areas with the non-removable highlight.

(a)

(b)

Figure 7: Another result of HiRemHDR approach. Image before highlight removal (a). Image after our algorithm has been applied, note the remaining highlight on the blue part of the racecar hood (b).

5 Conclusion and Future Work

In the article we have presented a global non-interactive method of highlight removal from HDR images. The experimental results given in subsection 4.2 illustrate the effectiveness of the proposed approach. Our method can be used as a preprocessing step for many image processing algorithms which require an input image without high luminance regions.

As mentioned in subsection 4.2 HiRemHDR is not fully effective for low luminance highlights. Adding user interaction and applying our algorithm locally could address this issue. However, HiRemHDR proved to be successful in most of the cases. Even if not all of the highlights are removed it still removes high luminance areas (e.g. to support tone mapping).

The proposed method can also be improved by adding adaptive polynomial coefficients. These coefficients could be acquired from the analysis of highlight regions. Currently HiRemHDR utilizes a static coefficients, which proved to give satisfying result in most cases.

Also, the method can be amended by employing better color histogram equalization algorithm. Pichon et al. [3] showed adaptive histogram equalization which can be useful. Premiliminary research in this direction will be conducted shortly.

The other issue is the removal of highlights from textured surfaces, HiRemHDR does not deal with those problem very well. It would require a more elaborate approach. Image inpainting seems a good solution as proven by Tan et al. [7] in his article and authors have already begun work with this particular method. The results of preliminary research seem promising.

There seems to be many ways of improvement to HiRemHDR and we plan to verify them in our future work.

6 Acknowledgement

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