A High Dynamic Range Imaging Algorithm Based on Moving Objects Processing

Jiun-You Chen, Chen-Chung Liu
Department of Electronic Engineering, Chin-Yi University of Technology
 gn00139173@yahoo.com.tw, ccl@ncut.edu.tw

Abstract

High dynamic range (HDR) image can faithfully present real world scenes to be widely utilized in surveillance, remote sensing, and space research fields. This paper proposes an effective scheme to synthesize multiple low dynamic range (LDR) images of a scene with different exposures to a single HDR image, and to manipulate the moving objects appearing in some original LDR images to enhance the quality of the final output HDR image. The proposed algorithm first detects where the moving objects locating in each input LDR images and divides the moving-object-free area of each LDR images into unoverlapped blocks with the same size, then evaluate each block's average intensity and the statistical values of intensities of whole the LDR images. The proposed gives weight for each block according each block's average intensity. The final output block is assigned as a weighted sum of the input blocks acquired at different exposures. The experimental results show that the proposed algorithm is a simple and high effective HDR imaging scheme with three advantages: (i) the proposed algorithm is time saving, due to operates completely on intensity plane only, (ii) the ghost artifacts in the resultant HDR image can completely be removed or clearly preserved, (iii) there are no restrictions in the image dynamic color ranges in the proposed algorithm.

Keywords: High dynamic range (HDR), low dynamic range (LDR), ghost artifacts.

1 Introduction

In photography, the definition of dynamic range depends on what the dynamic range refers to. The dynamic of a scene is the brightness ratio of the brightest part to the darkest part, and the dynamic of a display is the ratio of the maximum luminance to the minimum luminance emitted from the screen, and the dynamic of an image is the ratio of the brightness of the brightest part to the darkest part of the image [1, 2]. An image or a scene is called to be HDR while its dynamic range extremely exceeds the dynamic range of the capture or display device. Real-world scenes are often HDR due to they can always contain a very enormous range of light intensities at the same time. For instance, in a sunny day we want to take a photograph that contains the inside of a room and some exterior scenes visible through windows. In most cases, the exterior scenes will be very bright due to the sun’s directly illuminating, while the illumination of the inside of the room is far darker. In order to make features in the dark areas visible, one may use higher exposure to acquire an image, which displays appropriately exposed details in the room and renders the bright area saturated to lose all details of the exterior scene. On the other hand, one may utilize lower exposure to properly expose the exterior scenes to make features in the exterior scenes visible, but the interior of the room will be underexposed to lose all details of the room [2, 3].

In fact, traditional LRD imaging cannot completely display all the detail features of a scene that are detected by human visual system. On the other hand, with the rapid progresses in computer graphing and digital imaging technologies, people have been increasing interests in HDR imaging [4]. HDR imaging offers the capture of faithful representations of real world scenes to become a powerful technique in many areas; in medical imaging, it provides the maximum amount of detail data for radiologists to exam medical MR images. In digital photography, it produces preferred pictorial images, faithfully reproduces overall appearance of original scenes and the contrast relationships between objects in the scene, and predicts the visibility of specific objects in a scene [5]. Now, HDR imaging is widely utilized in surveillance, remote sensing, and space research. Many researches have shown that HDR imaging has much better performances than that of LDR imaging in these areas mentioned above.

The main purpose of HDR imaging is to accurately represent the real world scenes with a large range of brightness from the brightest sunlight to the darkest shadow. Now, there are many methods to obtain the so-called HDR images : (i) being created directly with Computer-generated ; (ii) obtaining from modern
imaging-hardware, advanced HDR-CCD digital cameras are combined with two different exposure CCDs so they can get the HDR that is four times of the traditional camera’s HDR: (iii) generating by combining the information from multiple LDR images taken at different exposure settings [6, 7]. The third method is the most popular and most effective, it detects saturated pixels in the images and compensates these saturated pixels with the pixels of the images taken under other exposure conditions before images combining. People can easy set the optimal exposure conditions to improve dynamic range through exposure time control due to the exposure time can be controlled accurately.

The most popular method to generate HDR images is to sequentially take multiple images of the scene using different exposures; High exposures provide useful information in dark scene regions and low exposures offer useful information in dark scene regions. Therefore, these different exposed images can be fused to get a single HDR image. To acquire HDR images from combining multiple LDR images was first reported by Mann & Picard [8]. They examined the situation of each different exposure image of a scene to give weight for each image, and merged these weighted images to form a single HDR image. Chen and Mu [9] proposed an interactive cut-and-paste scheme to increase images’ dynamic ranges, where blocks of the resultant image are manually selected from blocks of the input images.Debevec and Malik [10] utilized multiple exposures to increase the dynamic range of images. They gave higher weight to input pixels whose intensities are nearer to the mean of all the pixels of input images, and less weight to the input pixels whose intensities are farer away the mean of all the pixels of input images. The final output pixel is specified as a weighted average of the input blocks acquired at different exposures. Additional works about still HDR imaging have been done by Mitsunaga & Nayar [11], Robertson et al [12], and Robertson et al [13].

We propose a simple and effective scheme to generate a single HDR image combined by multiple LDR images of a scene with different exposures; the method is an extension merging of Chen et al method and Debevec et al method. Our scheme does not need to estimate the response function of the image capture device. We first divide each LDR images into unoverlapped blocks with the same size, then evaluate each block’s average intensity and the statistical values of intensities of whole the LDR images. Our algorithm gave higher weight to blocks whose average intensities are nearer to the mean of all the corresponding blocks that are at the same place in the result image, and less weight to blocks whose average intensities are nearer to the mean of all the corresponding blocks that are at the same place in the result image. The final output block is assigned as a weighted average of the input blocks acquired at different exposures. Moreover, those ghost pixels in HDR image are (i) synthesized with the residual LDR images for moving objects removing, and (ii) replaced by the moving objects for moving objects preserving. The experimental results show that the proposed algorithm is effective and validated. The remainder of this paper is organized as follows: Section 2 presents the proposed algorithm. Section 3 describes the Empirical results. Section 4 concludes this paper.

2 Proposed object extraction algorithm

The overall process of the proposed HDR imaging scheme for color images is shown in FIGURE 1. The input RGB color images of a scene with different exposures are transformed into HSI color space. The proposed scheme first detects which input images include moving objects and which pixels are located by moving objects. The moving-object-free pixels are rearranged into unoverlapped blocks with the same size, then evaluate each block’s average intensity and the statistical values of intensities of whole the HSI images. Our algorithm gave higher weight to blocks whose average intensities are nearer to the mean of all the corresponding blocks that are at the same place in the result image, and less weight to blocks whose average intensities are nearer to the mean of all the corresponding blocks that are at the same place in the result image. The final output block without moving objects is assigned as a weighted average of the input blocks acquired at different exposures. For those ghost pixels in HDR image (i) are synthesized with the residual LDR images for moving objects removing, and (ii) are replaced by the moving objects for moving objects preserving. Some basic theory about the brightness of a scene and steps of the proposed algorithm are described detail in the following subsections.
3 Scene Brightness

The observed brightness of a scene is referred as luminance, measured in candela (cd) per square meters [1]. For example, the surface of the sun has an intensity about $2 \times 10^5$ cd/m², a moonless night sky has a luminance level about $3 \times 10^{-4}$ cd/m², and a daylight scene is close to $10^3$ cd/m² [2]. The dynamic range of brightness (radiance) values approximately $10^{12}$:1 for a typical real-world scene, $10^{15}$:1 for human eyes after adapting, up to $8 \times 10^7$:1 for camera sensor, and less than $10^5$: 1 for monitor. Although the HVS has a dynamic range of brightness approximately twelve orders of magnitude to distinguish huge range of light intensities in the real world scene. But the current performance of modern digital image capture and display devices still suffer from a limited dynamic range. These devices are called LDR reproduction devices in this paper. Digital cameras utilized in computer vision usually offer 8 bits of brightness information for each color channel at each pixel. For each color channel, all radiance intensities in the scene are mapped to one of 256 image brightness levels. Computer vision problems, such as the shape detection of objects, the motion estimation of objects, and the recognition of objects, are often under-controlled and thus essentially hard to be solved. The low dynamic images produced by today’s LDR reproduction devices make dark areas darker and make bright areas brighter to loss more features to cause each of these problems more difficult.

4 Color model transformation from RGB to HIS

The RGB model is the most popularly used color model in measuring or reproducing color [14]. However, it is not suitable for image processing applications because its R, G, and B components are highly correlated. In image processing and analysis, these R, G, and B components are often transformed into other color models. Modern techniques for HDR imaging are basically developed on the RGB color space. Luminance- chrominance color space representations are frequently neglected. On the other hand, employing HDR imaging techniques in luminance- chrominance space may better for the following reasons: (i) The intensity channel of Luminance- chrominance color space is a weighted average of the R, G, and B channels which may not be the true colors. In this paper, we address the HDR imaging in HIS color space to improve the performance of HDR imaging [15]. The HIS (Hue, Saturation, and Intensity) color model is the most representative of the perceptual systems, its
components \( H \) (hue), \( I \) (intensity), and \( S \) (saturation) are transformed from the RGB color space by the following equations [16].

\[
H = \begin{cases} 
\theta & \text{if } B \leq G \\
360 - \theta & \text{if } B > G 
\end{cases}
\]

(1)

\[
\theta = \cos^{-1} \left[ \frac{1/2[(R - G) + (R - B)]}{[(R - G)^2 + (R - B)^2(G - B)]^{1/2}} \right]
\]

(2)

\[
S = 1 - \frac{3}{(R + G + B)} \min(R, G, B)
\]

(3)

\[
I = \frac{1}{3} (R + G + B)
\]

(4)

In the HSI color model the saturation corresponds to the relative purity of a color. The hue stands for the dominant wavelength in mixed light and indicates a dominant color as perceived by the human eye. The intensity or perceived lightness indicates the brightness of a color.

5 Moving Objects Processing

Most classic schemes to create HDR images always suppose static scene to register multiple images taken under different exposures. Due to moving objects change their locations among exposures, if the same schemes are utilized in a scene with moving objects then the resultant HDR image will have ghost artifacts in the pixels where moving objects had appeared. A method to solve this problem is to detect those ghost pixels previously, and then to generate the HDR image without including those ghost pixels and finally to replace those ghost pixels in HDR image with the estimated radiance values. In this paper, we first sort the multiple intensity normalized LDR images into a sequence according the mean intensity of each intensity normalized LDR image, then determine the intensity difference maps between any two adjacent intensity normalized images, and finally filter the intensity difference maps with a thresholding filter to detect the candidate ghost pixels and their corresponding intensity normalized LDR images. In the following HDR image synthesis step, (i) those ghost pixels in HDR image are synthesized with the residual LDR images for moving objects removing, (ii) those ghost pixels in HDR image are replaced by the moving objects for moving objects preserving.

6 HDR image synthesis

Due to the fact that the hue and saturation planes of different exposure images of a scene are the same, the proposed algorithm does not change the hue and saturation planes to maintain their original colors. For estimating the combination weight of each intensity plane, the mean and standard deviation of intensity of the set of \( N \) different exposure images of a scene are evaluated by the following equations:

\[
\mu_i = \sum_{x=1}^{W} \sum_{y=1}^{H} I_i(x, y) / (W \times H),
\]

(5)

\[
\mu = \sum_{i=1}^{N} \mu_i / N,
\]

(6)

\[
\sigma = \sqrt{\sum_{i=1}^{N} \sum_{x=1}^{W} \sum_{y=1}^{H} (I_i(x, y) - \mu)^2 / (N \times W \times H)},
\]

(7)

where \( I_i(x, y) \) is the intensity of pixel \( p_i(x, y) \) in the image \( i \), \( W \) is the width and \( H \) is the height of the input image, and \( N \) is the number of images of the set of \( N \) different exposure images of a scene. The proposed algorithm divides each intensity plane into unoverlapped blocks with the same size \( m \times n \), evaluates each block’s average intensity, and then determines each block’s combination weight using following equations.

\[
\nu_i(j, k) = \sum_{x=j}^{j+m-1} \sum_{y=k}^{k+n-1} I_i(x, y) / (m \times n), j = 0, 1, 2, ..., [W / m], k = 0, 1, ..., [H / n],
\]

(8)

\[
\omega_i(j, k) = \exp\left(-\left(\nu_i(j, k) - \alpha \mu\right) / \sigma^2\right) / \sum_{i=1}^{N} \exp\left(-\left(\nu_i(j, k) - \alpha \mu\right) / \sigma^2\right),
\]

(9)

where \( \nu_i(j, k) \) is the average intensity of block \((j, k)\) of image \(i\), \( \omega_i(j, k) \) is the combination weight of block \((j, k)\) of image \(i\), and \(\alpha\) is the adjustment coefficient with value between 0.1 and 1. The intensity of a block of the result HDR image is the weighted sum of intensities of corresponding blocks that located
at the same place, and the intensity plane of the resultant HDR image is the composition of these result intensity blocks.

6 Experiments

This section presents experimental results under various conditions to illustrate the utility and efficiency of the proposed scheme. Figure 2 shows a HDR imaging example with the proposed algorithm for a window scene which is moving object free. Row 1 shows five input LDR images of a static window scene taken at different exposure times, from brightest to darkest are 1/13, 1/25, 1/50, 1/100, and 1/200 seconds by using a Nikon D5100 digital camera with aperture f/8. Row 2 shows five corresponding output HDR images of these input window scene images generated at different adjustment coefficients, from left to right are 0.2, 0.4, 0.6, 0.8, and 1. Row 2 shows that both indoor and outdoor scenes are clearer while the different adjustment coefficient is decreasing, such that more detail features can be detected. Row 3 shows four corresponding output HDR images of the red-swatch image of (c1) while generated with different block sizes, from (c2) to (c5) are 3×3, 4×4, 6×6, and 8×8 pixels. Row 3 shows that the visible quality of the result HDR image is largely depend on the block size, the edges of objects in the HDR image is smoother while the size of blocks is decreasing.

Figure 2. An example of the proposed HDRI algorithm for a static window scene.

Figure 3 shows another HDR imaging example with the proposed algorithm for a static scene with a moving hand; (a1) ~ (a2) show five input LDR images taken at different exposure times, (b1) shows the corresponding output ghost-including HDR image of these input images generated at block size 4×4 (ghost is indexed by a red circle), (b2) shows the corresponding output moving-object-preserving HDR image of these input images generated at block size 4×4 (moving-object is indexed by a red circle), (b3) shows the corresponding output moving-object-deleting HDR image of these input images generated at block size 4×4 (moving-object-deleting region is indexed by a red circle). Figure 3 shows that not only the visible regions are preserved, but also the overexposed and underexposed areas in the original LDR images are modified suitably in the result HDR image. In addition, the ghost artifacts in the original HDR images are removed completely, or the moving-object is effectively preserved.
Figure 3. An example of the proposed HDRI algorithm for an indoor scene which contains a moving mouse.

7 Conclusion

High dynamic range (HDR) image can faithfully present real-world scenes to be widely utilized in surveillance, remote sensing, and space research fields. This paper proposes an effective scheme to synthesize multiple low dynamic range (LDR) images of a scene with different exposures to a single HDR image, and to manipulate the moving objects appearing in some original LDR images to enhance the quality of the final output HDR image. The proposed algorithm first detects where the moving objects locating in each input LDR images and divides the moving-object-free area of each LDR images into unoverlapped blocks with the same size, then evaluate each block’s average intensity and the statistical values of intensities of whole the LDR images. The proposed gives weight for each block according each block’s average intensity. The final output block is assigned as a weighted average of the input blocks acquired at different exposures. The experimental results show that the proposed algorithm is an effective HDR imaging scheme with three advantages: (i) the proposed algorithm is time saving, due to operates completely on intensity plane only, (ii) the ghost artifacts in the resultant HDR image can completely be removed or clearly preserved, (iii) there are no restrictions in the image dynamic color ranges in the proposed algorithm. In the future, we will combine the proposed scheme color transform schemes to improve the qualities of generated HDR image.

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References


