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Image dynamic range compression by combining gamma-corrected images

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Abstract: A dynamic range compression technique is necessary for displaying high dynamic range images on display devices having low dynamic range. This paper presents a new dynamic range compression method using gamma corrections. Gamma corrections with different gamma coefficients are first applied to the observed image to generate several candidate images. Then, the proposed method produces the result image by adequately combining them according to the weight functions based on local variances. The local variances are used as local weights to bring out the detailed information. Experimental results demonstrate that the proposed method compresses the dynamic ranges of images by bringing out the details not only in dark region but also in bright region.

1. Introduction

Recently, high dynamic range (HDR) images have been widely used for various purposes such as medical tomography, industrial monitoring system, surveillance system, computer vision system, scientific research applications, broadcasting system, consumer appliances, etc [1]. The HDR images can be obtained by either using HDR imaging systems or HDR reconstruction method based on signal processing. The HDR imaging systems capture HDR images directly, and the HDR reconstruction method restores an HDR image from low dynamic range (LDR) images. It requires multi-frame images of the same scene, which are taken with different exposure times [2]. Although HDR images are useful in many applications, most of the current display devices cannot fully display the detailed information of HDR images, since the dynamic ranges of them are much smaller than those of the images obtained in the HDR environment. Therefore, a dynamic range compression technique is necessary to display HDR images on LDR display devices.

In order to show the information of HDR images as much as possible under the LDR environment while maintaining the images visually pleasing to the user, a number of dynamic range compression algorithms have been studied [3]-[10]. In this paper, we propose a new dynamic range compression method using gamma corrections. First, gamma corrections with different gamma coefficients are applied to the observed image to generate several gamma-corrected images. Then, the proposed method adequately combines them according to the weight functions based on the local variances. The local variances are used to bring out the detailed information. The local variance becomes larger as the details in local area become visible. Therefore, the local area which has the largest local variance should dominantly influence on the result image among the candidate images. As a result, the local variances are used as local weights to compress the dynamic range.

This paper is organized as follows. The characteristics of gamma corrections and the detailed implementation of the proposed method to combine several candidate images are presented in Section 2. The experimental results of the proposed method are presented in Section 3.and the paper is concluded in Section 4.

2. Image dynamic range compression by combining gamma-corrected images

In this section, we introduce the characteristics of gamma corrections, and explain the detailed implementation of the proposed method.

2.1 The characteristics of gamma corrections

Gamma correction is a non-linear operation used to compress and expand luminance values in imaging systems. Gamma correction is defined by the following power-law expression:

$$Y = \left(\frac{X}{255}\right)^{\frac{1}{\gamma}} \times 255, \tag{1}$$

where X and Y are the input and output values, respectively. These values are non-negative real values. In the 8-bit digital image, the range of values is from 0 to 255. The case $\gamma > 1$ is often called gamma compression, and $\gamma < 1$ is called gamma expansion.

The proposed method uses gamma corrections to compress dynamic range. Figure 1 illustrates the characteristics of gamma corrections. Figure 1 (a) is an example of an image in which dark and bright regions coexist. Figure 1 (b) and (c) are the results of gamma compression and gamma expansion achieved with Fig. 1 (a), respectively. As shown, the gamma compression effectively brings out the detailed information in dark region. However, the details in bright region are saturated toward white. On the contrary, the gamma expansion effectively brings out the detailed information in bright region. However, the details in dark region are diminished. Therefore, if the results of gamma compression and gamma expansion are adequately combined according to the characteristics of the regions, we can bring out the details in both dark and bright regions at the same time, that means the compression of dynamic range. That is, the concept of the proposed is to generate several gamma-corrected images as candidate images for final compression result, and combine them according to weight functions.

2.2 The choice of gamma coefficients

Gamma coefficients determine the degree of dynamic range compression. However, if extremely strong compression is

Figure 1. (a) The original image. (b) The result of gamma compression : γ=2.0. (c) The result of gamma expansion : γ=1/2.0.

performed, it causes the degradation of visual contrast. Therefore, desirable gamma coefficients should be chosen to generate several candidate images according to the characteristics of the input images. The proposed method uses two candidate images, one is gamma compressed image for compressing dark region, the other is gamma expanded image for compressing bright region. The input image is divided into dark and bright regions to decide gamma coefficients. Then, the mean of each region is calculated as

$$M_d = \sum X(i,j)/N_d, \quad if(X \leq x_m), \tag{2}$$

$$M_b = \sum X(i,j)/N_b, \quad if(X \geq x_m), \tag{3}$$

where X is the input image, (i,j) is the location of pixels in X. x_m is the middle point which is the criteria for dividing the regions. M_d and M_b are the means of dark and bright regions. N_d and N_b are the number of pixels included in each region, respectively.

M_d has the value from zero to x_m, and M_b has the value from x_m to 255. If M_d is close to zero, it implies that the pixels included in dark region are crowded near zero. In this case, strong gamma compression should be applied. On the other hand, if M_d is close to x_m, it indicates that the pixels included in dark region are crowded near the middle point x_m. In this case, the gamma coefficient should be close to 1, which corresponds to no compression. In the same manner, if M_b is close to 255, strong gamma expansion should be applied. Also, if it is close to x_m, the gamma coefficient close to 1 should be chosen for gamma expansion. Considering these properties, the proposed method selects the gamma coefficients as the functions of differences between the mean of each region and x_m. We model these functions as

$$\gamma_c = \alpha \sin\left(\frac{(x_m - M_d)\pi}{2x_m}\right) + 1, \tag{4}$$

$$\frac{1}{\gamma_e} = \alpha \sin\left(\frac{(M_b - x_m)\pi}{2(255 - x_m)}\right) + 1, \tag{5}$$

where γ_c and γ_e are the gamma coefficients for gamma compression and expansion, respectively, and α is a weight.

α controls the strengths of gamma curves. Therefore, α should be chosen by considering dynamic ranges of display devices. For the devices, which need a stronger compression, α should be high, while for the devices, which need a weaker compression, α should diminish towards 0, which corresponds to no compression.

2.3 The local weights for dynamic range compression

For each pixel position, the local variances are used as local weights to bring out the detailed information. Figure 2 illustrates the relationship between the details in local areas and the local variances. Figure 2 (a), (c), and (e) are the partially magnified images of Fig. 1 (a), (b), and (c), respectively. These figures show one part of dark regions at the same location in each image. Figure 2 (b), (d), and (f) are the partially magnified images of Fig. 1 (a), (b), and (c), respectively. These figures show one part of bright regions at the same location in each image. As shown, gamma compression brings out the detailed information in dark region, while gamma expansion diminishes them in that region. That is, the result of gamma compression shows better performance than that of gamma expansion in dark region for the purpose of dynamic range compression. On the contrary, gamma expansion brings out the detailed information in bright region, while gamma compression diminishes them in that region. Bringing out the detailed information in local area means the increase of local variances. Therefore, the local variance becomes larger as the details in local area become visible. As a result, if we use local variances as local weights, the result of gamma compression dominantly influences on the output image in dark region, and that of gamma expansion dominantly influences on the output image in bright region. That is, the proposed

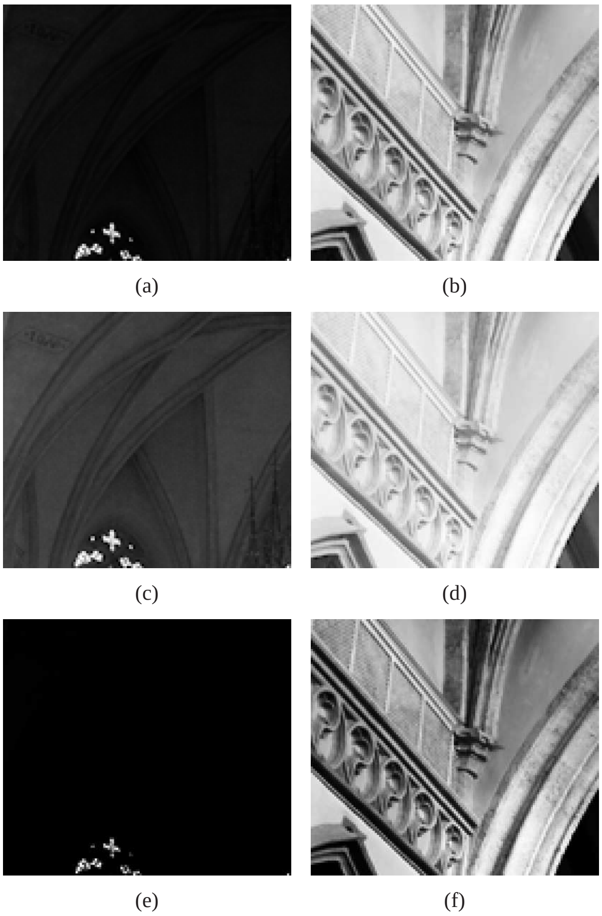

Figure 2. (a),(b) Partially magnified images of Fig. 1 (a). (c),(d) Partially magnified images of Fig. 1 (b). (e),(f) Partially magnified images of Fig. 1 (c).

method can compress both dark and bright regions at the same time by adequately combining candidate images.

To generate candidate images, gamma corrections with different gamma coefficients, which are chosen by equation (4) and (5), are applied to the observed image. From these images, the local variances are defined as

$$V_c = \frac{1}{N} \sum_{(i,j)\in H} (G_c(i,j) - M_c)^2, \tag{6}$$

$$V_e = \frac{1}{N} \sum_{(i,j)\in H} (G_e(i,j) - M_e)^2, \tag{7}$$

where G_c is the image, which gamma compression with γ_c is applied. G_e is the image, which gamma expansion with γ_e is applied. V_c and V_e are the local variances of G_c and G_e, respectively. H is a local window, and N is the number of pixels in H. (i,j) is the location of pixels in H. M_c and M_e are the local means of G_c and G_e, which are defined as

$$M_c = \frac{1}{N} \sum_{(i,j)\in H} G_c(i,j), \tag{8}$$

$$M_e = \frac{1}{N} \sum_{(i,j)\in H} G_e(i,j). \tag{9}$$

Finally, the output image where local weights are used is produced by combining G_c and G_e. It is expressed in equation as

$$Output_L = \frac{V_c \times G_c + V_e \times G_e}{V_c + V_e}. \tag{10}$$

When both V_c and V_e are zero at the same time, V_c and V_e are altered to different values to avoid dividing by zero as

$$V_c = BV_c \; and \; V_e = BV_e, \quad if(V_c = 0 \; and \; V_e = 0), \tag{11}$$

where BV_c and BV_e are the latest non-zero values among the previous V_c and V_e, respectively. BV_c and BV_e are defined as

$$BV_c = \acute{V_c}, \quad if(\acute{V_c} \neq 0), \tag{12}$$

$$BV_e = \acute{V_e}, \quad if(\acute{V_e} \neq 0), \tag{13}$$

where $\acute{V_c}$ and $\acute{V_e}$ are the previous local variances.

3. Experimental results

In order to demonstrate the performance of the proposed method, we present some simulation results (”church” image of 480×640 size) in this section. During the simulation, α which controls the strengths of gamma curves was varied, and the calculations of the local means and variances were carried out in the 3×3 local window. Figure 3 (a) is the original ”church” image which is taken by a digital camera. In this figure, most of the objects in dark region are not clearly visible. As shown in Fig. 1 (b) and (c), if only gamma compression is applied to the image, the details in dark region become noticeable but it causes the saturation of the signals in bright region. On the other hand, if only gamma expansion is applied, the details in bright region become vivid but it causes the loss of the signals in dark region. The proposed method exploits the advantages of candidate images by using the local weights. Figure 3 (b)-(d) is the results of the proposed method. As shown, the proposed method significantly enhances image quality by bringing out the details not only in dark region but also in bright region.

4. Conclusion

We have presented a new method for compressing the dynamic range in this paper. The goal of dynamic range compression is to show the information of HDR images as much as possible under the LDR environment. For the purpose of dynamic range compression, we use gamma corrections that is simple and computationally efficient. First, the input image is analyzed to choose proper gamma coefficients. Then, gamma corrections with different gamma coefficients are applied to observed image to generate several candidate images. The proposed method combines them according to the weight functions based on local variances. The local variances are used as local weights to bring out the detailed information. Simulation results show that the proposed method produces visually good results in terms of dynamic range compression.

(a)

(b)

(c)

(d)

Figure 3. (a) The original image. (b) The result of the proposed method : α=0.5. (c) The result of the proposed method : α=1.0. (d) The result of the proposed method : α=1.5.

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