REDUCING ILLUMINATION BASED ON NONLINEAR GAMMA CORRECTION

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ABSTRACT

Illumination always affects image quality seriously in practice. To weaken illumination effect on image quality, this paper proposes an adaptive Gamma correction method. First, a mapping between pixel and Gamma values is built. The Gamma values are then revised using two non-linear functions to prevent image distortion. Experimental results demonstrate that the proposed method performs better in readjusting image illumination condition and improving image quality.

***Index Terms*—** Illumination, Gamma correction, Image enhancement

1. INTRODUCTION

The illumination incident on a scene always is one of the most important factors that directly reduce the performance reliability of many computer vision systems. For example, in object tracking systems, many algorithms often fail when the illumination of backgrounds changes with objects moving from one scene to another. Moreover, in many face recognition systems, the changes in illumination always are intolerant in practice. Therefor, weakening the effect of illumination effectively is essential in many cases.

Recently, some algorithms have been developed to diminish the effect of illumination on images, such as color constancy method [1, 2], color similarity measure [3, 6], color space transformation [5, 7], histogram equalization [8] and traditional Gamma correction [9] and so on. However, these methods have their own limits in reducing illumination. For color constancy, establishing a reasonable illumination model always is impracticable in many cases. Color similarity measure is usually inapplicable under significantly changing illumination. For color space transformation, the absolute separation between chrominance components and luminance components is not achievable due to the correlation of color channels. So this method is successful only if the light condition with minor changes. For histogram equalization, many unsmoothed blocks often are yielded in equalized images, and this situation can become worse especially when the images are illuminated seriously. Compared to the above methods, Gamma correction method (GCM) exhibits some adaptability in illumination reduction, since the Gamma values can be selected manually according to the real illumination conditions. In this method, every pixel of an image illuminated improperly is corrected using a fixed Gamma value. However, it is often difficult to select suitable Gamma values without the prior knowledge about the illuminations. Moreover, the varieties of images greatly challenge the performance of the traditional GCM in applications.

In order to correct images effectively and automatically without prior illumination knowledge, this paper proposes an adaptive Gamma correction method (A-GCM). First, an mapping is built between Gamma values and pixel values. The Gamma values are then readjusted nonlinearly to obtain a reasonable smooth Gamma curve. Finally, pixels are corrected adaptively using the readjusted Gamma values. The experiments demonstrate that the proposed A-GCM have good performance in reducing illumination.

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2. INTERVAL MAPPING

The relationship between pixel values and Gamma values is established using a conformal mapping. Assume that $\mathbf{P}$ denotes the pixel interval $[0, 255]$, $\mathbf{\Omega}$ does the angle interval $[0, \pi]$, $\mathbf{\Gamma}$ does the Gamma interval, x does a pixel value. Let x_m be the middle point of $\mathbf{P}$. Thus, the mapping from $\mathbf{P}$ to $\mathbf{\Omega}$ is defined as

$$\begin{gathered} \varphi : \mathbf{P} \rightarrow \mathbf{\Omega} \\ \mathbf{\Omega} = \{\omega | \omega = \varphi(x)\} \\ \varphi(x) = \pi x / 2x_m \end{gathered} \quad (1)$$

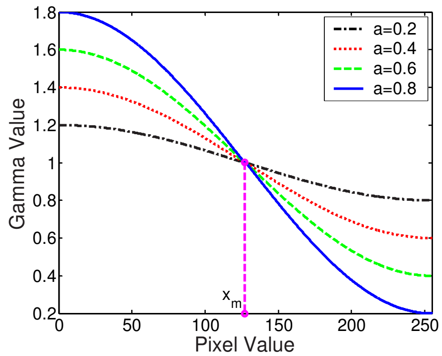
The mapping from $\mathbf{\Omega}$ to $\mathbf{\Gamma}$ is then defined as

$$\begin{gathered} h : \mathbf{\Omega} \rightarrow \mathbf{\Gamma} \\ \mathbf{\Gamma} = \{\gamma | \gamma = h(x)\} \\ \begin{cases} h(x) = 1 + f_1(x) \\ f_1(x) = a\cos(\varphi(x)) \end{cases} \end{gathered} \quad (2)$$

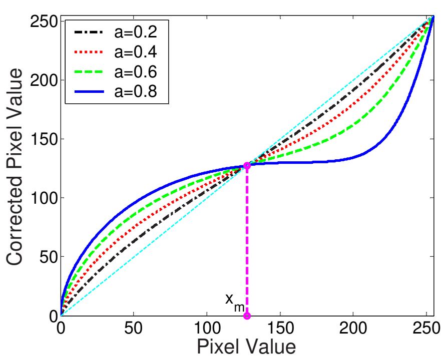
where $a \in (0, 1)$, is a weight. From the two mappings, we can see that $\mathbf{P}$ is corresponding to $\mathbf{\Gamma}$. Hence, any pixel can be assigned a corresponding Gamma value. Let $\gamma(x) = h(x)$ and $g(x)$ be the Gamma correction function, $g(x)$ is defined as

$$g(x) = 255(x/255)^{1/\gamma(x)} \tag{3}$$

Thus, the corrected value of a pixel is determined by its own pixel value. Some Gamma value curves and corrected pixel value curves are illustrated in Fig. 1.



(a) Gamma value curves



(b) Corrected pixel value curves

Fig. 1. Gamma correction.

From Fig. 1(a), we can see that Gamma-value curves vary with the values of a. The variation of a Gamma-value curve directly determines the corrected pixel-value curve (see Fig. 1(b)). Fig. 1(b) also shows that the pixels with low values become brighter after Gamma correction, whereas the pixels with high values become darker. Hence, Eq. 3 are capable of dealing with the illumination in a flexible manner to an image. That is to say, the proposed GMC is capable to lighten shadows while darken highlights in images automatically. This meets the requirement of correcting an image adaptively and automatically without prior knowledge about its illumination.

Generally, broader interval $\mathbf{\Gamma}$ can make the Gamma-value curve more applicable to illumination variation. However, broadening $\mathbf{\Gamma}$ purely based on the increase of a can directly results in a bigger fluctuation of the Gamma values (see Fig. 1(a)). This readily brings pixel distortion after Gamma correction as shown in Fig. 1(b), where a pixel-value curve behaves impractically when a is 0.8. From Fig.1(b),we can find that the values of pixels near x_m are corrected greatly too, which does not conform with the fact of the diffuse reflection of light. The pixels around x_m belong to midtones generated by light diffusion, so improper correction on these pixels can directly result in image distortion. Hence, in order to adaptive diminish the effect illumination properly, we must revise the shape of Gamma-value curve.

3. GAMMA VALUE REVISION

Besides shadows and highlights in an image captured in real lighting condition, there are an transition region or midtones, with better light condition due to the diffuse reflection of light. Obviously, the shadows, highlights and midtones should be corrected in different manners. Less correction, even no correction, to the midtones is beneficial to improve the quality of an image. Hence, two functions are used to revise Gamma values aiming to implementing less correction to pixels in midtones and more correction in shadows and highlights.

The first function is defined as

$$\begin{aligned} f_2(x) &= (K(x) + b)\cos\alpha + x\sin\alpha \\ &\begin{cases} K(x) = \rho\sin(4\pi x/255) \\ \alpha = \arctan(-b/x_m) \end{cases} \end{aligned} \tag{4}$$

where ρ represents the amplitude of $K(x)$, α is the rotation angle of $K(x)$, b bounds the variation of $f_3(x)$. The curve of $f_3(x)$ is illustrated in Fig. 2.

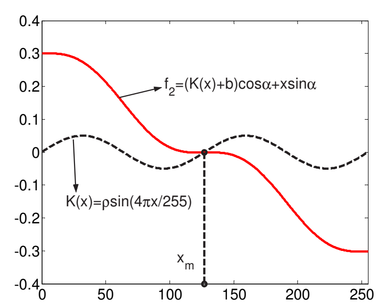


Fig. 2. Sine curve with rotation.

From Fig. 2, we can see that $f_3(x)$ is capable to revise $f_1(x)$ with different manners corresponding to shadows, midtones and highlights as well as broadens $\mathbf{\Gamma}$.

The second function is defined as

$$\begin{aligned} f_3(x) &= R(x)\cos(3\pi x/255) \\ R(x) &= c|x/x_m - 1| \end{aligned} \tag{5}$$

where c represents the amplitude of $R(x)$ and bounds the variation of $f_3(x)$. The curve of $f_3(x)$ is illustrated in Fig. 3, where c is 0.3.

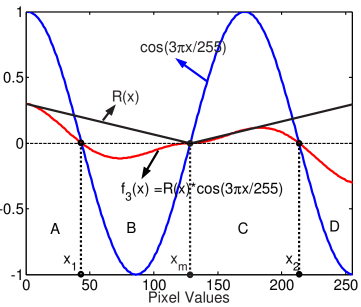


Fig. 3. Cosine curve with amplitude variation.

Fig. 3 shows that the value of $R(x)$ decreases gradually from the two ends of $\mathbf{P}$ to x_m, and $f_3(x)$ with amplitude variation due to $R(x)$ has three zero-cross points: x_1, x_m x_2, and $\mathbf{P}$ is divided by the three points into four sub-intervals denoted by A, B, C, D respectively. Consequently, the Gamma values can be readjusted by $f_3(x)$ in different manners. That is, the absolute Gamma values corresponding to A and D increase, whereas the ones corresponding to B and C decrease. This is beneficial to improve image quality since the pixels in shadows and highlights are corrected greater than the ones in midtones. Hence, a combination of $f_1(x)$, $f_2(x)$ and $f_3(x)$ is defined as

$$G(x) = f_1(x) + f_2(x) + f_3(x) \tag{6}$$

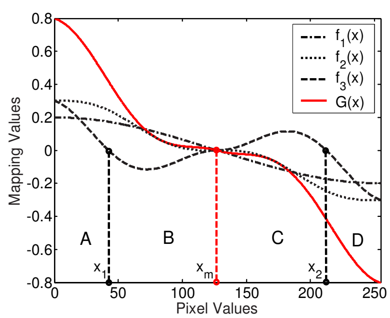


Fig. 4. Combination of non-linear curves.

The curve of $G(x)$ goes steeply downhill in A and D respectively and does gently in B and C respectively as shown in Fig. 4. Thus, the revised Gamma function is defined as

$$\tilde{\gamma}(x) = 1 + G(x) \tag{7}$$

For A-GCM, the Gamma values must be positive, so a necessary and sufficient condition for $\tilde{\gamma}(x) > 0$ is $a+b+c < 1$. Generally, $a < b \leq c$ is best for A-GMC since this can assure that the initial Gamma values determined by $f_1(x)$ vary little, $f_2(x)$ can broaden $\mathbf{\Gamma}$ properly, and $f_3(x)$ is able to further readjust the Gamma values for improving their adaptivity to illumination changes.

4. EXPERIMENTS AND DISCUSSION

From the above Sections, we can see that $f_1(x)$ generates the initial Gamma values whose interval $\mathbf{\Gamma}$ is determined directly by a, $f_2(x)$ broadens $\mathbf{\Gamma}$ by readjusting the initial Gamma values in the consideration of shadows, midtones and highlights, and $f_3(x)$ is a key function making the Gamma-value curve more reasonable to deal with illuminations in practice. Fig. 5 and Fig.6 illustrate them intuitively, where $a = 0.2$, $b = 0.3$, $c = 0.3$, and the dashed lines are free to $f_3(x)$.

From Fig. 5, we can see that x_1, x_m and x_2 also represent three inflexions of the revised Gamma-value curve, so the variation manners of the Gamma values are different in A, B, C and D. This can make the proposed A-GCM capable of correcting pixels accounting of shadows, highlights as well as avoiding image distortion due to improper correction to midtones (see Fig. 6). Hence, the proposed A-GCM holds obvious advantages to improve image quality by reducing illumination adaptively. For a color pixel, the proposed A-GCM are performed independently for its R, G and B components.

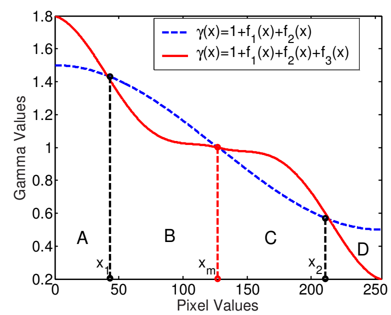


Fig. 5. Revised Gamma curve.

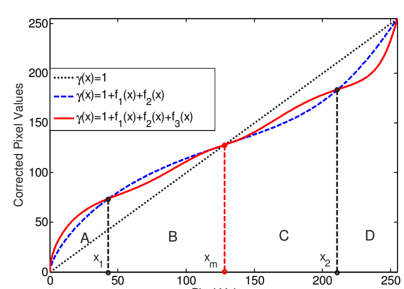


Fig. 6. Corrected pixel curve with revision.

Fig. 7 gives a comparison between the traditional method and the proposed method in correcting an image. To clearly show the differences between the original and the corrected image histograms, we place them in the same plot, as shown in the last row of Fig. 7. The histogram with magenta color corresponds to the original image, the other to the corrected image. The traditional techniques shown in left and middle columns demonstrate that whether a Gamma value is less or greater than one, the histogram of an image is only adjusted in one fashion. Hence, the traditional Gamma correction is limited to improve the quality of an image. The proposed A-GCM shown in right column illustrates that an image is corrected bidirectionally since its histogram is adjusted aggregately to the center of grey levels. Hence, the proposed A-GCM is capable of weakening the effect of illumination on an image adaptively. Also, we see that the appearance of the corrected image in the top of right column seems to be taken under an relative proper illumination.

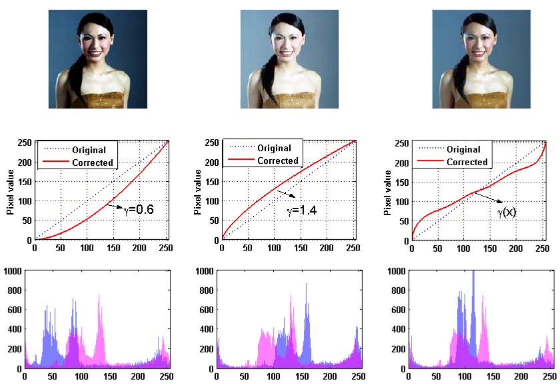
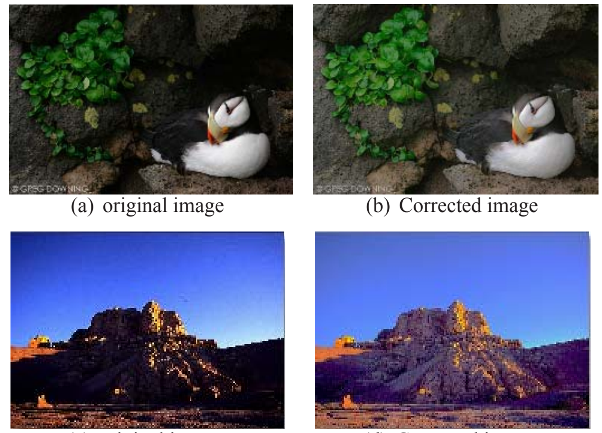


Fig. 7. Gamma correction method comparison.

Fig. 8 give more examples using the proposed A-GCM to correct color images. Fig. 8(a) and Fig. 8(c) are two original images with different illuminations, and Fig. 8(b) and Fig. 8(d) are two corrected images corresponding to the original images respectively. Obviously, the illumination conditions in the two corrected are improved greatly. Fig. 9 gives the result of a grey image from Yale face database using the proposed A-GCM. The corrected image in right column appear better than the original image in left column.

5. CONCLUSIONS

An adaptive Gamma correction method was proposed in this paper. First, the relationship between Gamma values and pixel values was established by interval mapping. Then, the initial Gamma values were readjusted by two nonlinear functions in order to make the Gamma-value curve more suitable to real illumination conditions in images. So the proposed A-GCM was able to improve illuminations in shadows, midtones and highlights simultaneously. The experiments have shown that the proposed A-GCM performed well in improving image quality.



(a) original image (b) Corrected image

(c) original image (d) Corrected image

Fig. 8. Adaptive Gamma correction for color image.

Fig. 9. Adaptive Gamma correction for grey image.

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