A Novel Tone Mapping Method Based on Retinex Theory

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Abstract: - Tone mapping is an important technique in image processing. In this paper, a novel tone mapping method based on Retinex theory is proposed. Since many existing algorithms are time consuming, multi-scale analysis is used in this algorithm to reduce the computational time. In addition, in order to improve performance, we use three Gaussian constants for a single filter instead of a traditional fixed Gaussian constant. At last, an error computation method is given. According to this error, we can evaluate the tone mapping algorithms not only subjectively but also objectively. The experimental results show that our algorithm is effective and timesaving. At getting same or even better image quality condition, our algorithm consumes much less time than other algorithms.

Key-Words: - tone mapping, center/surround Retinex, dynamic range, wavelet

1 Introduction

The goal of tone mapping is to display images that approximate to those that directly observe scenes. The dynamic range is the luminance ratio between the brightest and the darkest object in a scene, when the dynamic range of the obtained image is not in that of the display device range, tone mapping technique needs to use. Various image processing techniques have been developed. Some of those techniques are simple spatially-independent methods, such as gamma adjustment, logarithmic compression and histogram equalization. However, those simple methods are based global processing and generally have very limited performance. Therefore, advanced techniques were proposed based on a deeper under-standing of human vision system which is much more capable of handling scenes with non-standard dynamic ranges [1].

Multi-scale Retinex (MSR) is an effective tone mapping technique, which is based on the well known Retinex theory that was proposed by E. Land [4] as a model of human visual perception of lightness and color. Z. Rahman [2] used Multi-scale spatial convolution to obtain luminance information for tone mapping and achieve a balanced result bet-ween local contrast and dynamic compress range. Except for MSR, other Retinex-based algorithms were also proposed such as [5]. Laurence Meylan [8] developed a Retinex-based adaptive filter tone mapping method, which consists of two parts: a glo-bal tone mapping and Retinex-based local processing. The adaptive filter whose shape follows the image high contrast edges instead of a fixed surround shape is used. In this way, the influence of applying a filter on different color- band is reduced, but it brings out a significant increase in computational complexity. According to the problem mentioned above, we propose two solutions to reduce the computational time as well as to retain the important image information. The first solution is to get a quarter size of image via wavelet transformation. The second solution is the major novel idea of our paper, in Meylan's paper [8], the value of weighted average of the treated pixel's surrounding is determined by image edge, if an edge is crossed along the radial direction, Gaussian constant is assigned a smaller one, for each new radial direction Gaussian constant is reset its initial value. The implement processing is very complex for the use of iterative processing, that is, for one pixel, it must be processed four times of same operation. In this paper, we propose another method based on this algorithm and also define another Gaussian constant between the initial one and smaller one. Due to the drawback of Canny operator, which can not make a distinction between texture edges and object boundaries, and makes the processing computation is very expensive, we do not use edge controlling. Indeed, if the edge can actually locate the high contrast, it will indeed improve the processed image well with less time consuming.

The organization of the paper is as follows. A brief overview of the Retinex theory is presented in Section 2. In section 3, our algorithm with three Gaussian constants into a single filter is proposed.

The effectiveness of the proposed approach is verified by the experiments on several images in section 4. Concluding remark is given in section 5.

2 The Retinex Theory of Color Vision

The Retinex theory, developed by Edwin Land, intends to explain how the visual system extracts reliable information from the scene despite the changes of illumination [4]. He concluded with experiments that relative reflectance is more important than absolute reflectance and proved that the color of a pixel was determined by the relationship between this pixel and the neighborhood pixels in each color-band. A version of Retinex called center/surround was also proposed by Land, a large number of tone mapping methods take inspiration from it. Based on this theory, Jobson and Rahman [2] developed a method called Single-scale Retinex (SSR), its form is given by

$$R_i(x,y) = \log I_i(x,y) - \log[G(x,y) * I_i(x,y)] \quad (1)$$

where $R_i(x,y)$ is the Retinex output, $I_i(x,y)$ is the image distribution of the *ith* color spectral band at the location (x,y), "$*$" denotes the convolution operator, $G(x,y)$ is the surround function whose spatial constant plays a role in the final result, that is, there is a trade-off between dynamic range compression and tonal rendition, which is decided by the Gaussian surround spatial constant. Since SSR is incapable of simultaneously providing sufficient dynamic range compression and tonal rendition, Multi-scale Retinex is adopted, its definition is as follows.

$$R_i(x,y) = \sum_{k=1}^{K} W_k \{\log I_i(x,y) - \log[G_k(x,y) * I_i(x,y)]\} \; (i = 1..N) \quad (2)$$

where the sub-index *i* denotes the *ith* color band, *N* is the number of color bands and *N=3* is typical value for color image. G_k represents the *kth* surround function with a spatial constant. W_k is the weight associated with G_k, *K* is the number of surround functions, "$*$" denotes the convolution operator as that of in the SSR. Later, they added a color restoration for reducing the gray-out problem, but the problem yet remains.

3 A Tone Mapping Algorithm with One Filter

In this section, we present a tone mapping algorithm that can improve the image captured by the limit dynamic range camera. It belongs to the version of center/surround Retinex algorithms and is based on the algorithm developed by Meylan [8] whose adaptive filter's shape follows the image high contrast edges instead of a circularly-symmetric Gaussian filter. The high contrast edges map is obtained by Canny operator, the Canny operator can not make a distinction between texture edges and object boundaries, and also makes the processing time very expensive. However, the notion of reducing the influence between the different illumination objects is remarkable. So we define another Gaussian constant between the initial one and smaller one. Moreover, a square domain is defined instead of circle domain, which can scan pixel row-by-row rather than scan every radial direction from the central pixel with iterative way.

3.1 Preprocess

Every pixel in the image is treated by the same way. In order to reduce the computational time as well as retaining important image information, we use the wavelet transformation to get a quarter size of original image. After processing, the image is re-gained using bilinear interpolation method. As we can see in Fig.1, the low frequency part of the image is reserved as the processed image.

(A) original (B) after transformation

Fig.1 wavelet transformation

Instead of applying to the R, G. and B color channel respectively. In Meylan's paper [8], she performed a principle component analysis (PCA) for obtaining luminance on the input image and proved that the luminance transformed via PCA is decorrelated from the chrominance, which allows the color to remain relatively unchanged despite of the performance on the luminance. So in our algorithm, PCA is also used.

3.2 Global Processing

The goal of global tone mapping is to model the early stage of the Human Vision System non-linearity where a global tone mapping function takes place, and the curvature of the function that determined the adaptation result depends on the mean luminance of the total field of view [3].For the mean luminance of the image, we use region-growing method that segments the image on condition that all pixels in one region having similar luminance value for removing the noise influence.

$$I = D^1 + D^2 + ... + D^{num} = \sum_{j=1}^{num} D^j \quad (3)$$

$$I_{av} = \frac{\sum_{i=1}^{num} D^{ave}(i)}{mum} \quad (4)$$

where D denotes the segmented region, *num* is the number of regions. $D^{ave}(i)$ is the *ith* region's mean luminance. Non-linear luminance $I^{'}$ is given by

$$I^{'}(p) = I^{r}(p) \quad (5)$$

where p is the value of one pixel. In order to compare our algorithm with Meylan's [8], we also use the same formula (6), I_{av} is just obtained using our method mentioned above.

$$r = \min(1, \frac{1}{6} I_{av} + \frac{2}{3}) \quad (6)$$

The formula mentioned above shows that if I_{av} is larger, that is, the image is bright and it does not need global compression, otherwise if I_{av} is smaller, it will increase dark areas detail information using compressing process.

3.3 Local Processing

After global processing, local processing is performed using a center/surround Retinex method, Traditionally, center/surround Retinex method computes a new value for each pixel by taking the difference between the log-encoded treated pixel and the weighted average of the treated pixel's surrounding area. In this paper, we use mask represents the later value. How to compute the mask? There are lots of methods, which are critical for the whole process, we pay attention to its significance and put forward a new method that using a filter with three Gaussian constant parameters, the number of parameters may be large. As most of algorithms use three parameters, we also adopt this way.

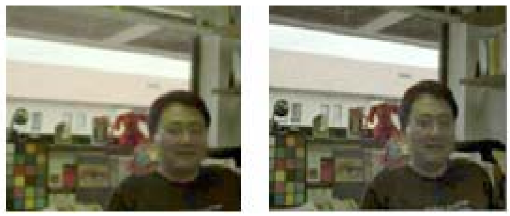
The influence of neighborhood pixels on the central pixel should be reduced along with the distance between the center pixel and surround pixel increasing. The mask function is given by

$$mask(x,y) = \frac{\sum_{i=-dis/2}^{i=dis/2} \sum_{j=-dis/2}^{j=dis/2} I^{'}(x+i, y+j) \cdot e^{\frac{-r^2}{\delta^2}}}{\sum_{i=-dis/2}^{i=dis/2} \sum_{j=-dis/2}^{j=dis/2} e^{\frac{-r^2}{\delta^2}}} \quad (7)$$

where $r^2 = i^2 + j^2$, dis^2 denotes the area of square and we serve the treated pixel as the center point, δ is the spatial constant, the weighted sum of pixels is normalized by the sum of weights so that each pixel has an equal contribution to the mask value.

4 Experiment Results

Our algorithm is based on the Retinex-based adaptive filter algorithm of Meylan [8]. It is natural to make a comparison with her algorithm's results. Our algorithm aims to reduce the computational complexity as well as retain the color rendition.



(A) our result (B) meylan's result

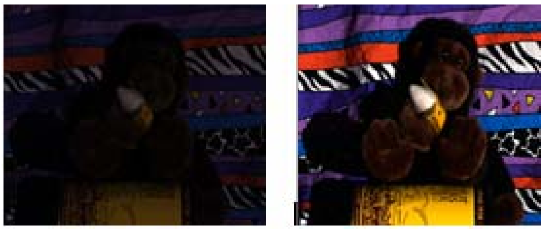
Fig.2 comparison result

Fig.2 compares an image treated by our algorithm with the same image treated using adaptive filter. It is difficult to tell which one is more visually appealing. Considering the numerous existing tone mapping algorithms, since each of the algorithms has different strengths and weakness, it is difficult to draw general conclusions, so we choose the test image from a database that includes the measured light source color value [7]. We can adjust the processed image to that of under canonical illuminant and serve it as scale standard. In this process, the diagonal model [6] is needed. We serve the light source color as R_c, G_c and B_c ,then the scaling coefficient of the three channels is $(255/R_c, 255/G_c, 255/B_c)^T$, which is used for obtaining the image under canonical illuminant. We can use the mean angular error between the output image c and the canonical image c_{nor} .

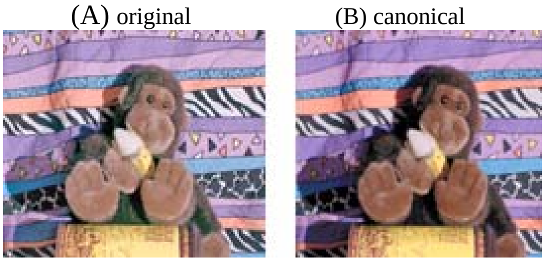
$$\arg error = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \cos^{-1}(\hat{c}(i,j) \bullet \hat{c}_{nor}(i,j))}{n \times m} \quad (8)$$

where $c(i,j)$ represents color vector composed by the R,G and B value of the pixel at the location (i,j) in the image. $\hat{c}(i,j) \bullet \hat{c}_{nor}(i,j)$ denotes the dot product of two normalized vectors $c(i,j)$ and $c_{nor}(i,j)$. $n \times m$ is the number of pixels. As we known, the smaller is the result, the closer is the direction between the two vectors.

In the experiment, the parameters in our algorithm are evaluated as: *dis*=20, δ values are 5, 10 and 15, we choose six images to test our algorithm. Fig.3 compares the images obtained with the two methods, we can find that the image (D) treated with our algorithm has a good color rendition than image (C).With mean angular error method, we compute the angular error comparing with the canonical image, the comparison result (as image 1 shown in Table 1) is 14.57 degree and 14.89 degree and there are four images are better than those using the other method.



(A) original (B) canonical



(C) meylan's result (D) our result

Fig.3 comparison result of image 1

Fig.4 shows another two images treated with our algorithm. The angular errors of them are larger than other images, but the adjusted effect is still much better.

(A) original (B) our result

Fig.4 examples of image 2 and 6

5 Conclusion

In this paper, we propose a new tone mapping method for rendering images based on Retinex theory. Most of methods can give satisfying results for images. However, more time consuming is involved in large number of methods. According to the problem, we put forward a new way based on the algorithm approved by Meylan [8]. Then we propose a new method to evaluate algorithm's quality. The experimental results show that our algorithm is effective and also has low computational costs. Since high frequency information lost caused by wavelet transformation, how to combine with the wavelet enhancement technique will be investigated in our future work.

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Table 1 Statistical mean angular error (degree) for six images on the data set.

	Image 1	Image 2	Image 3	Image 4	Image 5	Image 6
our algorithm	14.57	18.98	4.30	17.60	8.35	19.09
adaptive algorithm	14.89	18.86	4.40	17.97	8.14	20.16