AUTOMATIC DIGITAL IMAGE ENHANCEMENT FOR DARK PICTURES

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ABSTRACT

An automatic method is presented to enhance the visibility of dark areas of an image while preserving its natural look. This method consists of three major parts: classification, global adjustment and local adjustment. Firstly, an image is classified into one of several types for different global/local processing or no processing. The method adaptively maps a luminance value into a value based on a piecewise linear mapping curve in order to increase contrast in dark areas. The global and local mapping curves are based on histogram equalization with modifications. The local enhancement is non-overlapped block-based and is applied only when necessary. To avoid blocking artifacts generated by block-based local adjustment, the luminance value of each pixel is adjusted according to an interpolated mapping curve derived from the block mapping curves of nearby blocks. The combination of global and local enhancements achieves good overall enhancement with local adaptability without excessive complexity.

1. INTRODUCTION

The quality of digital camera images is largely affected by the light condition at the shooting time. In some cases, the whole picture is very dark. In some other cases, the bright area is very bright, while the dark area is too dark to see any details. Automatically enhancing these dark pictures and dark areas is desirable for applications like digital camera.

One of the most popular image enhancement methods is Histogram Equalization (HE) [1], which is based on the histogram of the whole image to obtain a transform function that stretches or compresses the pixel levels to result in a uniformly distributed histogram. HE is simple, but it may over adjust and make images look unnatural. There are many variations of HE [2]-[4]. They are all only based on the global histogram of an image, therefore cannot adapt to local needs in small areas. Another technique which is often used to increase the contrast of dark areas is gamma processing. In [5], a neural-network method was proposed to automatically determine the gamma value. This method may make bright areas overly bright, and it does not adapt to details in small areas either.

It is sometimes desired to enhance the contrast of small dark areas that are usually neglected by global contrast enhancement. Among local automatic contrast enhancement techniques, local histogram equalization is an effective technique [1], [6], [7]. It usually uses a moving window to collect local histogram information, and performs histogram equalization to the center pixel of this window. The window is then moved to the next pixel. Since local histogram equalization must be performed to all pixels in the entire image, its complexity is very high. To reduce the complexity, non-overlapped block-based histogram equalization can be used. The problem of this non-overlapped block-based approach is severe blocking artifacts. In order to mitigate this problem, Kim al et [7] proposed to use partially overlapped blocks with low-pass filtered histogram for local histogram equalization. However, this method is still complicated due to the calculation of moving-window histograms and the low-pass filtering of the histograms.

In this paper we propose a combined global/local enhancement technique to enhance the dark areas of an image with reasonable complexity while maintaining the natural look of images. This paper is organized as follows: the proposed method is addressed in Section 2. Some examples are shown in Section 3, followed by conclusions.

2. THE PROPOSED METHOD

An image is first divided into many non-overlapped blocks. The size of the blocks is selected according to the desired size for local adaptability. For example, a 1M-pixel (1024x768) image can be divided into 16x12 number of blocks. Each block is of 64 by 64 pixels. In a one-pass histogram analysis, both global and local blocks' histograms are obtained by counting the number of luminance pixels falling into allocated histogram bins. These histograms are used in the following classification, global enhancement and local enhancement.

2.1. Classification

According to the statistics of the global and local histograms and some empirical thresholds, a picture is classified into one of several types. For example, one type of pictures contains plenty of bright pixels, not many dark pixels, and no dark blocks. These are regarded as normal pictures, and no adjustment is needed. A dark block refers to a block whose majority of pixels is darker than a predetermined threshold.

The rest of pictures that need enhancement can be further classified into several different types for fine tune of the processing to achieve robust enhancement without generating objectionable artifacts or distortions. For example, one type of pictures can have a histogram that contains a large percentage of dark pixels as well as a large percentage of bright pixels. For example, the main object of the image is dark while the background is very bright. It may be desirable to preserve the bright tone of those bright areas. We can then generate a luminance mapping, which enhances the dark pixels, but makes no change to the bright pixels.

In another example, one type of pictures can contain predominantly mid-range pixels and few very dark or very bright pixels. A typical example of this type of pictures is a picture with large smooth areas, such as background. Since the histogram of these pictures can be very concentrated in a few values, the usual HE approach may over stretch the concentrated values and amplify the noises in the large smooth areas. Several techniques are possible to avoid the problem. For example, a brightness offset can be used to increase the visibility of dark areas without amplifying the noise in the smooth areas.

For the rest of the paper, we will neglect these fine tunes of the processing and focus on the basics of our method.

2.2. The Global Enhancement

The pixel level mapping is done in YUV color space, and is performed to the luminance – Y only. The mapping consists of several continuous piecewise linear lines, which can be represented by a few pivot points. With the piecewise linear mapping, one can easily calculate the pixel level look-up table on the fly. This piecewise linear simplification has some similarity to the method in [4]. One main difference is that we space our pivot points along the vertical (output) axis of the mapping curve, while the method in [4] spaces them along the horizontal (input) axis. Since the output is histogram equalized, spacing along this axis is usually well behaved, while spacing along the input axis may have collapsed pivot points if there is no pixel with values between two pivot points.

The starting point (0,0) and the ending point (*Ymax, Ymax*) can be fixed, where *Ymax* is the maximum value for luminance signal, e.g. *Ymax*=255 for 8-bit images. The other pivot points, called adjustable pivot points, are determined based on the principle of histogram equalization. We space out the adjustable pivot points along the vertical (output) axis of the mapping curve. For example, we can select a few target percentages of *Ymax* as the Y-coordinates of the pivot points. In our implementation, we choose 4 adjustable pivot points with target percentages of 10%, 25%, 50% and 75% respectively.

The Y-coordinate of a pivot point, denoted as *mapped_Y[i]* (i.e., the mapped luminance value), can be then straightforwardly calculated by

$$mapped\_Y[i] = Ymax * target\_percent[i], \qquad (1)$$

where i is the pivot-point index and *target_percent[i]* denotes the target percentage for the pivot point i.

Based on the principle of histogram equalization, the X-coordinate of a pivot point should be the least luminance value that the accumulated histogram reaches its target percentage. Hence, to calculate the X-coordinate of a pivot point, firstly, we calculate the target count of the pivot point, denoted as *target_count[i]*:

$$target\_count[i] = target\_percent[i] * total\_pixels, \qquad (2)$$

where *total_pixels* denotes the total number of pixels.

The X-coordinate of the pivot point i, denoted as *actual_Y[i]* (i.e., the actual or original luminance value), can be determined as follows:

actual_Y[i] = the minimal k such that

$$\sum_{j=0}^{k} histogram\,[j] > target\_count[i], \qquad (3)$$

where *histogram[j]* is the number of pixels with value j.

Thus, the coordinates of the pivot point i can be denoted as (*actual_Y[i], mapped_Y[i]*). To avoid mapping lines going up too steep and to better preserve the natural look of the images, the slopes of the mapping lines can be regulated by selected maximum slopes. To facilitate fast conversion of luminance values, a mapping look-up table can be calculated by linear interpolation between adjacent pivot points.

2.3. The Local Enhancement

For the local enhancement, the local block mapping curve for each non-overlapped block is first calculated in a way similar to the global enhancement but using its local (or block) histogram, instead of global histogram.

Next, the local mapped luminance value is obtained by interpolation. Due to the differences among local mapping curves of neighboring blocks, if all pixels inside a block are mapped by only using this block's own local mapping curve, blocking artifacts would often occur at block boundaries. To avoid blocking artifacts, the local mapped luminance value of a pixel is calculated by interpolating the mapping curves of its four nearby blocks.

As illustrated in Fig. 1, pixel A has four nearby blocks. Firstly, we obtain the four mapped values of its original luminance value according to the block mapping curves of those four nearby blocks. We denote these four mapped values as Y_ul, Y_ur, Y_bl, and Y_br for the upper left, the upper right, the bottom left and the bottom right blocks respectively. Let x and y denote, respectively, the horizontal and vertical distances from the pixel A to the center of its block, which is the bottom right block in this case. Let w and h denote the width and height of a block, respectively. Use Y_u and Y_b to denote the horizontally interpolated values of the upper two blocks and of the lower two blocks, respectively. Then the final mapped value of the pixel A for local enhancement, denoted as $local\_Y$, can be calculated by a weighted sum of Y_ul, Y_ur, Y_bl, and Y_br with weights inversely proportional to distances, namely:

$$Y\_u = Y\_ul*x/w + Y\_ur*(1-x/w)$$
$$Y\_b = Y\_bl*x/w + Y\_br*(1-x/w)$$
$$local\_Y = Y\_u*y/h + Y\_b*(1-y/h) \quad (4)$$

The effect of the interpolation of Y_ul, Y_ur, Y_bl, and Y_br is equivalent to using an interpolation of four nearby block mapping curves to map the original luminance value of the pixel A. This mapping-curve interpolation effectively avoids any blocking artifacts. Hence no de-blocking filter is needed and the blur usually caused by the de-blocking filter can also be avoided.

The performance of this mapping-curve interpolation approach is better than that of the approach proposed by Kim al et [7] in terms of avoiding blocking artifacts, while having similar complexity, if not lower. This interpolation approach also allows seamless local-enhancement skip, which will be described in the next subsection, such that the overall complexity of our method becomes lower than the method in [7].

2.3. The Combined Global and Local Enhancement

Compared to the global adjustment, the local adjustment is relatively expensive in terms of complexity. To lower the complexity, local adjustment can be skipped when it is not necessary. The local-adjustment skip is done on both the picture level and the block level. In order to determine the necessity of local adjustments, a local property about the darkness of each block is needed. The term "dark block" is as defined before in the Section 2.1. It refers to a block that a majority of the pixels in the block is darker than a threshold.

For the picture-level local-adjustment skip, we skip the local adjustment for entire image when the picture has the total number of dark blocks greater than a specified threshold. For this kind of pictures, since there are a lot of dark blocks, their histograms would be sufficiently represented in the histogram for the whole picture. Hence, global adjustment alone would be sufficient and the expensive local adjustments can be skipped.

For the block-level local-adjustment skip, the local adjustment is only applied to the dark blocks and the pixels near the dark blocks. Local adjustment curves are obtained for dark blocks only and the interpolations are performed for the dark blocks and their neighboring pixels in order to avoid blocking artifacts. For the rest of pixels in non-dark blocks, only global adjustments are performed. In the interpolation step, if a neighboring block's local mapping curve does not exist (i.e., the neighboring block is not a dark block), the global mapping curve is used instead. This will make a smooth transition between the blocks with local adjustment and those without local adjustment, therefore makes a seamless integration of the global and the local enhancements. Since local enhancement is only performed to a small number of blocks of an image, the complexity increase due to local enhancement is limited.

To overcome the over-enhancing problem that often occurs to a local adjustment method, for the blocks with local adjustment, the final mapped value of a pixel is obtained by the weighted average of its global mapped value and its local mapped value. From our experiments, the same weight for the global and the local adjustments gives good results. It achieves the local adaptability, while maintaining the global tone and natural look of an image.

3. EXPERIMENTAL RESULTS

Two example pictures are shown in Fig. 2. The original pictures are of 1M pixels and 2M pixels respectively. It can be easily seen that the adjusted pictures have much better detail visibility than the originals in the dark areas. In (b), the dark area is enhanced, while the bright areas are preserved. In (d), the detail visibility of the dark lower left corner is improved. This kind of small dark area is usually neglected by a global enhancement method. We have tested our algorithm on hundreds of pictures with satisfactory results.

4. CONCLUSIONS

An automatic contrast enhancement method is presented to enhance the detail visibility in dark areas of an image while preserving its natural look. We classify images into different types for appropriate processing. The major component of our method is based on Histogram Equalization (HE) with several modifications. One modification is the piecewise linear approach which simplifies HE and also enables simple interpolation for local enhancement. Another modification is the non-overlapped block-based approach for local adaptation. The main innovation of this paper is using interpolation of local mapping curves to avoid blocking artifacts. The interpolation of local mapping curves also prevents the blur that often occurs if a de-blocking filter is used. Our combined global/local enhancement preserves overall natural tone while allows local adaptation. Several modifications are made to keep the overall complexity low. The proposed method achieves good enhancement over a wide variety of digital images.

5. REFERENCES

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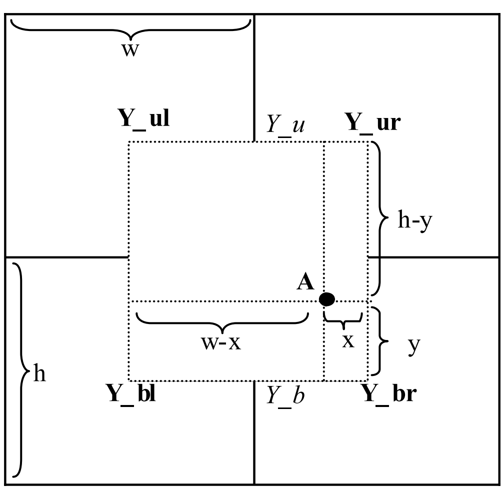

Fig. 1. Example of the Interpolation

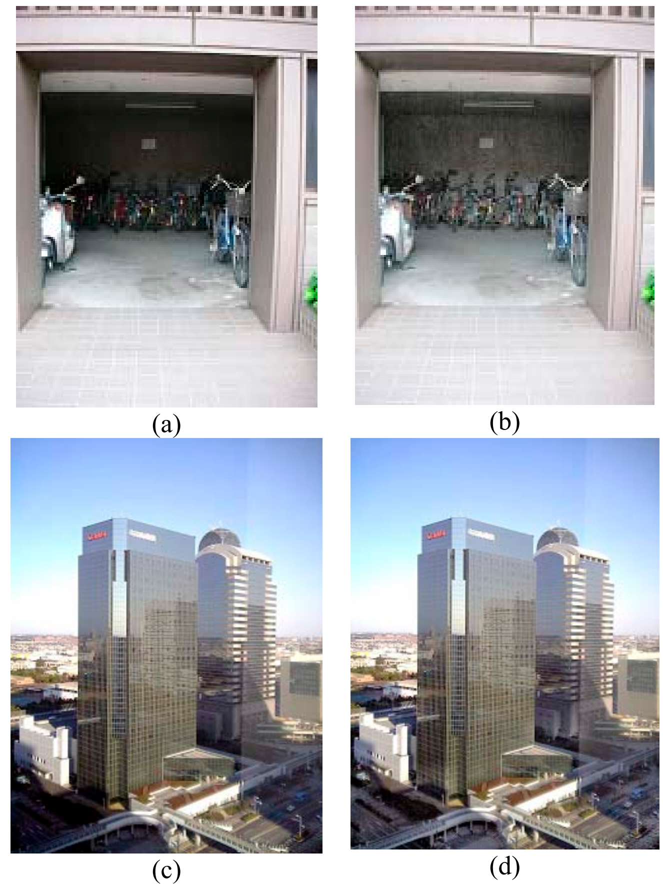

Fig. 2. Experimental results: (a) and (c) original pictures; (b) and (d) enhanced pictures