CONTRAST ENHANCEMENT WITH CONSIDERING VISUAL EFFECTS BASED ON GRAY-LEVEL GROUPING

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The poor quality of the used imaging devices, inexperienced operators, and the adverse external conditions during image acquisition also easily result in poor contrast [2]. Generally, the images with low or poor contrast only utilize a small portion of the dynamical range, and cannot reveal all detailed information. Contrast enhancement, as implied by the name, aims to raise the contrast of an image so that one can highlight the details of an image, but excessive enhancement will damage visual effects. Therefore, a good contrast enhancement method should keep visual effects while raising contrast as high as possible.

Histogram equalization (HE) is one of the most popular contrast enhancement methods, also the earliest contrast enhancement one. The goal of HE is to transform the histogram of an input image into a uniform distribution based on the occurrence of gray levels. In theory, the equalized image is supposed to be uniform [7], whereas the result is quite different from what we expect due to the discrete nature of a digital image. Annoying artifacts and unnatural visual effects are often induced in the output image enhanced by histogram equalization. Even worse, its average brightness is always towards the middle of gray levels independent of the characteristic of the input image, giving the transformed image a monotonic visual effect.

To avoid the monotonic characteristic caused by HE, Kim [9] proposed a brightness preserving bi-histogram equalization (BBHE) method, which first decomposes an input image into two subimages based on the mean of the input image and then equalizes the two histograms independently. His algorithm provides good brightness preservation. Similar to the concept of BBHE, Wang et al. [13] proposed dualistic sub-image histogram equalization (DSIHE), which divides an input image into two subimages based on the median of an image. The basic idea of the method is to maximize the entropy of an output image. In order to confirm the effectiveness of their method, the authors illustrated an image with a large portion of gray levels being at 0. They claimed that the quality of the images enhanced by DSIHE is better than that of BBHE in terms of the criteria of the mean, average information content (AIC), and background gray level (BGL).

For achieving the maximum brightness preservation, Chen and Ramli [5] proposed minimum mean brightness error bi-histogram equalization (MMBEBHE). They adopted the minimum of the absolute difference between an input and its
output mean values, called the absolute mean brightness error (AMBE), as a criterion to determine its corresponding threshold gray level to separate the input histogram. The role of the threshold gray level is the same as the mean value for BBHE, or the median value for DSIHE. Since this algorithm is time consuming, the authors used an effective integer-based way to compute AMBE recursively.

In order to achieve optimal brightness preservation based on the maximum entropy, Wang and Ye [11] proposed brightness preserving histogram equalization with maximum entropy (BPHEME), which applied histogram specification (HS) to obtain a specified histogram. This method maximizes the entropy under the input mean brightness constraint. BPHEME can enhance an input image while preserving the mean brightness, so it is very suitable for consumer electronics such as TVs.

Based on the implementation of HE, the probabilities of histogram components will determine the spacing between histogram components of the enhanced image, and then decide the quality of visual effects. Since annoying appearances are coming from wide spacing, HE easily produces unfavorable visual effects for low-contrast images with particularly high histogram components. For properly dealing with this type of potential problem and producing satisfactory results for a broad variety of low-contrast images, or being unable to automatically choose the control parameters, Chen et al. [6] proposed an automatic method for contrast enhancement, called the gray-level grouping (GLG). It can automatically choose a histogram distribution to optimize contrast according to the maximum average distance (AD) between pixels on the grayscale.

Although GLG can achieve their asserted effects for some cases like Phobos and an X-ray image of luggage with a high histogram component being on the leftmost side, it fails in the cases with a high histogram component being on the rightmost or in the middle. The problem still lies in the spacing between histogram components.

In a few years after BBHE being proposed, Chen and Ramli [4] also proposed an enhancement scheme called recursive mean-separate histogram equalization (RMSHE), along with MMBEBHE previously mentioned before. RMSHE can be viewed as an extension of BBHE. First, the mean of the whole histogram is taken as the only threshold gray level. Then the mean of each subhistogram is taken as the new threshold gray level in the corresponding region. This process is repeated \( r \) times, and totally generates \( 2^r - 1 \) threshold gray levels as well as \( 2^r \) subhistograms. As the iteration number increases, the mean brightness of the output image will converge to the one of the input image. Eventually, RMSHE will have no effect on contrast enhancement. Although the repeating nature of RMSHE may provide adjustable brightness preservation, choosing the number of appropriate iterations is still a challenge.

Similar to RMSHE, Sim et al. [10] proposed a technique to raise brightness preservation and enhance contrast, called recursive sub-image histogram equalization (RSIHE). The method uses the median, rather than the mean used by the RMSHE to separate an input histogram. RMSHE and RSIHE may generally improve the results enhanced by BBHE and DSIHE, but also invoke a potential problem of how to choose the optimal value of \( r \) and a serious limitation on the number of subhistograms being a power of two.

For taking control over the effect of HE, Abdul-lah-Al-Wadud et al. [1] proposed dynamic histogram equalization (DHE) to partition an image histogram into subhistograms based on the local minima of the smoothed histogram, assign a specified gray level range to each partition, and equalize them individually. Because DHE does not take brightness preservation into consideration, Ibrahim and Kong [8] further proposed brightness preserving dynamic histogram equalization (BPDHE). BPDHE first partitions the image histogram based on the local maxima of the smoothed histogram, instead of the local minima, then assigns a new dynamic range to each partition, and equalizes these partitions independently. Finally the output intensity is normalized to make the mean intensity of the resulting image equal to the input one.

On the other hand, Wang and Ward [12] proposed a convenient and effective mechanism to control the enhancement process, called the weighted thresholded histogram equalization (WTHE). The transformation function of WTHE is obtained by the following procedure: first decide a lower threshold and an upper threshold; if the values of the original probability density function (PDF) are larger than the upper threshold, then set the values of the transformation function as the upper threshold; if the values of the original PDF lie between the lower and upper thresholds, the values of the transformation function are equal to the ratio of the difference between the PDF and the lower threshold to the difference between the lower and upper thresholds, modulated by a power of \( r > 0 \); the other values of the original PDF as the lower threshold. Their results show more pleasing visual effects than other HE-based methods at the cost of contrast.

Each method mentioned above has its own function for its specified problem, but some common drawbacks still exist. For example, patchiness effects, washed-out appearances, or/and other artifacts are easy to emerge owing to the characteristics of implementation. Therefore, Chang and Chang [3] proposed a simple histogram modification scheme to resolve these potential problems. This scheme is appropriate for all histogram-related methods resorting to histogram equalization, histogram specification, and histogram redistribution like GLG.

In this paper, we propose an improved version of GLG to extend its applications to other types of histograms in order to obtain images with high contrast and pleasing visual effects.

II. GRAY-LEVEL GROUPING AND ITS VARIANT

I. GLG

Although HE is a simple and automatic technique for
contrast enhancement, HE always accompanies a drawback that its average brightness is always close to the middle of the gray scale, and usually brings us unnatural appearances and unpleasant visual artifacts due to excessive contrast enhancement. Most of HE-based techniques are automatic but have similar limitations as HE. On the other hand, although contrast stretching, histogram specification and some of HE-based techniques like WTME can achieve satisfactory visual effects, but they need some parameters to be regulated. In order to obtain a pleasing and automatic contrast enhancement technique, gray-level grouping was proposed [6].

GLG is an unconventional approach to the histogram-based contrast enhancement problem. Its aim is to obtain the maximum contrast using an automatic contrast enhancement algorithm, especially for low-contrast images like X-ray. The objectives of GLG include achieving a uniform histogram in the sense that histogram components are redistributed uniformly over the grayscale, utilizing the grayscale more efficiently, spreading histogram components over the grayscale in a controllable and/or efficient way, if necessary, handling histogram components of different regions of the grayscale independently in order to satisfy specific purposes, and finally being general and able to handle various kinds of images automatically.

The basic procedure of GLG includes three steps: grouping the histogram components of a low-contrast image into a proper number of bins according to a certain criterion, then redistributing these bins uniformly over the grayscale so that each group occupies the same segment, and finally ungrouping the previously grouped gray levels.

After finishing the presented automatic procedure mentioned above, GLG chooses the transformation function with the maximum average distance (AD), and then transform the original histogram into the new histogram according to the selected transformation function. It can usually produce a satisfying result, compared to other contrast enhancement methods on the images with a high histogram component being on the leftmost side. However, GLG is also easy to result in excessive contrast because the spacing between histogram components contributes much to the AD or standard deviation (SD) and the larger the spacing is, the higher the risk of visual deterioration.

2. A Variant of GLG

Our logic is very simple. In order to ensure good visual effects of an image, we must moderately sacrifice its contrast. That is to say, a trade-off between visual effects and contrast is seriously considered. For achieving the goal, we observed the implementation of GLG in detail and found out its potential risk lying in the spacing between histogram components. Thus, we impose an extra constraint, spacing, on choosing the desired transformation function. Its implementation is very easy. First we set an appropriate threshold for the maximum spacing without leading to blocking. We then pick all transformation functions with spacing smaller than or equal to the threshold. Finally, we choose the maximum AD from the qualified candidates. Experimental results show that 12 (for 8-bit images) is a suitable threshold for most images, which still retain high enough contrast without losing visual effects. It is easy to know that the larger the threshold is, the larger the contrast; the smaller the threshold is, the better the visual effects. If the threshold is larger than or equal to 255 (for 8-bit images), then no influence on the result happens. Therefore, we must lower the threshold to achieve more pleasing visual effects in some special cases, where the ratio of the highest histogram component to its adjacent one is particularly high.

III. EXPERIMENTAL RESULTS AND DISCUSSION

GLG was confirmed to be an automatic and effective by illustrating some low-contrast images with their particularly high histogram components on the leftmost end. Accordingly, we would like to know whether other low-contrast images are effective or not. In this section, we illustrate two images, Phobos and aircraft, with two versions: original and negative. These two images have different histogram characteristics, and thus we can easily see the efficacy of our improved GLG. The corresponding histograms of image Phobos and aircraft are displayed in Fig. 1 and 2. The number of histogram support on Phobos has 256, whereas aircraft only 139. The background gray level (BGL) of Phobos is at 0 (255 for negative), aircraft at 177 (78).

One of objectives of the negatives is to conveniently produce an image with a particularly high histogram component on the rightmost end, and then we use the newly produced image to test the performance under contrast enhancement. Another objective is to realize whether GLG is affected by inversely implementing. On the other hand, the image aircraft is used to test the performance of general low-contrast images under contrast enhancement, in which some relatively high histogram components are distributed inside the histogram, not on two boundaries. These four images are enough to verify that the original GLG has some limitations in implementation, and
further confirm that our improved version of GLG can be applied to a wide variety of low-contrast images. Their corresponding contrast enhancement images for Phobos are displayed in Figs. 3-4, and aircraft in Figs. 5-6. Table 1 provides five measures for Phobos in order to quantitatively compare our newly improved version with other three images, and Table 2 for aircraft.

These five common standard measures include the mean, AIC, BGL, average distance (AD) [6], and standard deviation (SD) [7]. The mean provides a criterion to determine whether the enhanced image is close to the original image. Its equivalence is called the AMBE, which is an important criterion for applications to consumer electronics. The AIC can measure the average information of an image; the larger the AIC is, the more details an image possesses. The BGL aims to provide a decision whether the principal gray level is shifted too much or not, especially for images with particularly high histogram components on the leftmost or/and rightmost ends. The AD and SD are for measuring the contrast values; the larger the AD or SD is, the higher the contrast.

Table 1. Comparisons for methods on Phobos.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>AIC</th>
<th>BGL</th>
<th>AD</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>image</td>
<td>31.73</td>
<td>3.51</td>
<td>0</td>
<td>26.70</td>
<td>69.32</td>
</tr>
<tr>
<td>HE</td>
<td>176.23</td>
<td>3.20</td>
<td>157</td>
<td>14.16</td>
<td>29.63</td>
</tr>
<tr>
<td>GLG</td>
<td>53.25</td>
<td>3.31</td>
<td>0</td>
<td>39.59</td>
<td>83.83</td>
</tr>
<tr>
<td>GLG*</td>
<td>47.27</td>
<td>3.31</td>
<td>35.67</td>
<td>76.62</td>
<td></td>
</tr>
</tbody>
</table>

* The improved version of GLG with a threshold being 12.

Table 2. Comparisons for methods on the negative of Phobos.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>AIC</th>
<th>BGL</th>
<th>AD</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>image</td>
<td>223.27</td>
<td>3.51</td>
<td>255</td>
<td>26.70</td>
<td>69.32</td>
</tr>
<tr>
<td>HE</td>
<td>176.55</td>
<td>3.20</td>
<td>255</td>
<td>50.92</td>
<td>101.33</td>
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<tr>
<td>GLG</td>
<td>195.24</td>
<td>3.05</td>
<td>255</td>
<td>41.99</td>
<td>86.20</td>
</tr>
<tr>
<td>GLG*</td>
<td>207.68</td>
<td>3.31</td>
<td>35.72</td>
<td>76.73</td>
<td></td>
</tr>
</tbody>
</table>

* The improved version of GLG with a threshold being 12.
For the negative of Phobos, Table 2 tells us that HE has the largest amount of contrast, and GLG is the second; nevertheless, Fig. 4 shows that HE or GLG seem like a painting with the paint flaking off, whereas our improved GLG appears to be a distinct and pleasing appearance. In addition to visual effects, Table 2 also tells us that the whole performance of our improved GLG is the best. The mean of the improved version is the closest to the original image, the AIC is the largest, and the contrast is also raised to 1.34 times on AD and 1.11 times on SD.

The histogram of image aircraft is another type of classic image with low contrast used for comparison in the literature, such as [8]. It is clear from Figs. 5-6 that our improved GLG indeed possesses better visual effects. Tables 3 and 4 also tells us that our improved GLG is superior to HE and the original GLG at the cost of contrast; the mean, AIC, and BGL are closest to the original one, but it still raises the contrast by 2.87 times on AD and 2.07 times on SD on average.

### IV. CONCLUSION

GLG is an automatic and effective contrast enhancement technique. It was proposed to raise the contrast of an image as high as possible through recombining histogram components of an image. It works well for some low-contrast images with a particularly high histogram component on the leftmost end, but fails in the cases where a particularly high histogram component is on the rightmost end and some high histogram components lie inside the histogram.

In order to extend its applications to other low-contrast images, we find out its potential limitations in the procedure of recombination. A key factor is that GLG easily makes the spacing between histogram components wide enough to destroy visual appearances of the enhanced image. We discover that an extra constraint on selecting an optimal transformation function facilitates to find out the most appropriate transformation function with taking visual effects into consideration.

In this paper, two classic images, covering a wide range of images, were illustrated to confirm that our improved version of GLG can effectively preserve good appearances at the cost of little contrast. These two images are entirely different and our improved GLG works well, which implies that our improved GLG can be widely used in a wide range of images in the future.

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REFERENCES


