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CONTRAST ENHANCEMENT AND VISUAL EFFECTS BASED ON GRAY-LEVEL GROUPING

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Key words: contrast enhancement, histogram equalization (HE), gray-level grouping (GLG), visual effect.

ABSTRACT

Contrast enhancement plays a crucial role in the field of image processing. Histogram equalization is a simple and automatic method for contrast enhancement. Conventional contrast-enhancement techniques, such as histogram specification and contrast stretching, require manual parameters to achieve satisfactory results. To automatically produce enhanced results for low-contrast images, a new histogram-based optimized contrast-enhancement technique, called gray-level grouping (GLG), was proposed. GLG performs satisfactorily in dark and low-contrast images and always increases the contrast values to a maximum. Extravagant contrast enhancement typically means sacrificing the visual effects of an image. Through scrutinizing the GLG procedure, we discovered potential limitations and observed that an extra constraint on GLG enabled effective production of satisfying appearances while preserving contrast at a maximum. Experimental results showed that a simple idea led to a considerable difference in visual effects.

I. INTRODUCTION

Contrast enhancement is a widely used technique in image processing. Low-contrast images can result from inadequate illumination, lack of dynamic range in the imaging sensor, and incorrect setting of the lens aperture during image acquisition [7]. Inferior quality of the imaging devices, inexperienced operators, and adverse external conditions during image acquisition also easily result in insufficient contrast [2]. Images with low contrast use only a small portion of the dynamic range and do not exhibit detailed information. Contrast enhancement means improving the contrast of an image to elucidate its details; however, excessive enhancement damages visual effects. Therefore, an optimal contrast-enhancement method should retain visual effects while sharpening contrast to a maximum.

Histogram equalization (HE) was the earliest contrast-enhancement method and remains the most widely used. HE transforms the histogram of an input image into a uniform distribution based on the occurrence of gray levels. In theory, an equalized image is uniform [7]; however, because of the discrete nature of a digital image, this is not the case in practice. Artifacts and unnatural visual effects are often induced in an output image that is enhanced using HE. Furthermore, regardless of the characteristics of the input image, the average brightness of an image enhanced using HE always approximates the average of gray levels; consequently, the transformed image exhibits a monotonic visual effect.

To avoid the monotonic characteristic caused by HE, Kim [9] proposed a brightness preserving bi-histogram equalization (BBHE) method; this first decomposes an input image into two subimages, based on the mean of the input image, and then independently equalizes the two histograms. The Kim algorithm facilitates favorable brightness preservation. Wang *et al*. [13] proposed dualistic sub-image histogram equalization (DSIHE), which divides an input image into two subimages based on the median of the input image. The idea underlying this method is to maximize the entropy of an output image. To confirm the effectiveness of their method, Wang *et al*. illustrated an image with a considerable portion of gray levels amounting to 0. They claimed that regarding the criteria of the mean, average information content (AIC), and background gray level (BGL), the quality of the images enhanced using DSIHE was superior to that of images enhanced using BBHE.

To achieve maximal brightness preservation, Chen and Ramli [5] proposed minimum mean brightness error bi-histogram equalization (MMBEBHE). They adopted the

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minimum of the absolute difference between the means of an input image and its output image, called the absolute mean brightness error (AMBE), as a criterion to determine its corresponding threshold gray level in order to separate the input histogram. The role of the threshold gray level is the same as the role of the mean value for BBHE, and the median value for DSIHE. Because this algorithm is time consuming, Chen and Ramli used an effective integer-based method to compute AMBE recursively.

To achieve optimal brightness preservation based on maximal entropy, Wang and Ye [11] proposed brightness preserving histogram equalization with maximum entropy (BPHEME), which applies histogram specification (HS) to obtain a specified histogram. This method maximizes the entropy under the input mean brightness constraint. BPHEME enhances an input image while preserving the mean brightness; therefore, it is suitable for use in consumer electronics such as TVs.

Based on the implementation of HE, the probabilities of histogram components determine the spacing between histogram components of the enhanced image and thereby determine the quality of visual effects. Since undesired appearances emanate from wide spacing, HE easily produces unfavorable visual effects for low-contrast images with particularly high histogram components. To address this problem and produce satisfactory results for a variety of low-contrast images, or to circumvent the inability to automatically choose the control parameters, Chen *et al*. [6] proposed an automatic method for contrast enhancement, called gray-level grouping (GLG). This method facilitates an automatic choice of a histogram distribution to optimize contrast according to the maximal average distance (AD) between pixels on a grayscale.

Although GLG achieved the asserted effects in several cases, for example, *Phobos* and an X-ray image of luggage with a high histogram component on the leftmost side, it failed in cases with a high histogram component on the rightmost side or between grayscales. The problem is still related to the spacing between histogram components.

A few years after BBHE was proposed, Chen and Ramli [4] proposed an enhancement scheme called recursive mean-separate histogram equalization (RMSHE), along with the aforementioned MMBEBHE. RMSHE can be considered an extension of BBHE. First, the mean of the entire histogram is adopted as the only threshold gray level. Subsequently, the mean of each subhistogram is adopted as a new threshold gray level in the corresponding region. This process is repeated r times, and generates $2^r - 1$ threshold gray levels in total, as well as 2^r subhistograms. As the iteration number increases, the mean brightness of the output image converges to that of the input image. Eventually, RMSHE exerts no effect on contrast enhancement. Although the repeating nature of RMSHE provides adjustable brightness preservation, choosing the number of appropriate iterations remains a challenge.

Sim *et al*. [10] proposed a technique similar to RMSHE to improve brightness preservation and enhance contrast, called recursive sub-image histogram equalization (RSIHE). The method involves using the median, rather than the mean (which is used in RMSHE) to separate an input histogram. RMSHE and RSIHE generally improve the results of images enhanced by BBHE and DSIHE, but also lead to two problems of choosing the optimal value of r and limiting the number of subhistograms to a power of two.

To effectively utilize the advantages of HE, Abdullah-Al-Wadud *et al*. [1] proposed dynamic histogram equalization (DHE) to partition an image histogram into subhistograms according to the local minima of the smoothed histogram, assign a specified gray-level range to each partition, and equalize each partition individually. Because DHE does not consider brightness preservation, Ibrahim and Kong [8] proposed brightness preserving dynamic histogram equalization (BPDHE). BPDHE first partitions the image histogram according to 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 mean output intensity of the resulting image is normalized to that of the input image.

Wang and Ward [12] proposed a convenient and effective mechanism to control the enhancement process, called weighted thresholded histogram equalization (WTHE). The transformation function of WTHE is obtained using the following procedure: First, determine a lower threshold and an upper threshold. If the values of the original probability density function (PDF) are higher 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, then 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 upper and lower thresholds, modulated by a power of $r > 0$. The other values of the original PDF are replaced with the lower threshold. Their results exhibited more satisfactory visual effects than other HE-based methods , only sacrificing a little contrast.

Each of the aforementioned methods exhibits a unique function addressing a specific problem, but several common drawbacks remain. For example, patchiness effects, washed-out appearances, and other artifacts easily occur because of the characteristics of implementation. Therefore, Chang and Chang [3] proposed a simple histogram modification scheme to resolve these problems. This scheme is appropriate for all histogram-related methods using HE, HS, and histogram redistribution, such as GLG.

In this paper, we propose improved GLG, extending its applications to other types of histogram to obtain images with high contrast and satisfactory visual effects.

II. GRAY-LEVEL GROUPING AND ITS VARIANTS

1. Gray-Level Grouping

HE is a simple and automatic method for contrast enhancement. However, its average brightness is always close to the middle of the gray scale; therefore, it typically leads to unnatural appearances. In addition, it easily brings about undesired artifacts because of excessive contrast enhancement. Most HE-based techniques are automatic but exhibit similar limitations as HE. Although contrast stretching, HS, and several HE-based techniques like WTHE achieve satisfactory visual effects, they require regulation of certain parameters. GLG was proposed as a satisfactory and automatic contrast enhancement technique [6].

GLG is an unconventional approach to the histogram-based contrast-enhancement problem. It is used to obtain the maximal contrast employing an automatic contrast-enhancement algorithm, particularly for low-contrast images such as X-ray images. The objectives of using GLG include achieving a uniform histogram (in the sense that histogram components are redistributed uniformly over the grayscale), using the grayscale more efficiently, spreading histogram components over the grayscale in a controllable and efficient manner, if necessary, handling histogram components of different regions of the grayscale independently to satisfy specific purposes, and finally, being generally applicable and suitable for automatically processing various types of images.

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

After completing the aforementioned automatic procedure, GLG performs a transformation function with the maximal AD, and then transforms the original histogram into a new histogram according to the selected transformation function. Compared with other contrast-enhancement methods, GLG typically produces satisfying results in images exhibiting a high histogram component on the leftmost side. However, GLG easily causes excessive contrast because the spacing between histogram components substantially contributes to the AD or standard deviation (SD), and the larger the spacing is, the higher the risk of visual deterioration becomes.

2. A Variant of Gray-Level Grouping

Our logic is simple; to ensure favorable visual effects of an image, it is necessary to sacrifice its contrast to some degree. In other words, a compromise between visual effects and contrast is required. In this research we observed the implementation of GLG and determined that its potential risk is attributable to the spacing between histogram components. Therefore, we imposed an additional constraint, spacing, on the process of performing the desired transformation function. Its implementation was easy; first, we determined an appropriate threshold for maximal spacing preventing any blocking. Subsequently, we selected all transformation functions with a spacing smaller than or equal to the threshold. Finally, we chose the maximal AD from the qualified candidates. Experimental results showed that 12 (for 8-bit images) was a suitable threshold for most images, which retained sufficiently high contrast without losing visual effects. According to the results, a higher threshold led to sharper contrast, and a lower threshold led to superior visual effects. If the threshold was higher than or equal to 255 (for 8-bit images), then the results were not affected. Therefore, we lowered the threshold to achieve more satisfactory visual effects in specific cases, where the ratio of the highest histogram component to its neighbor was particularly high.

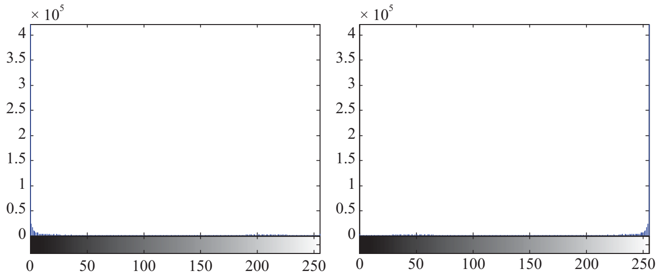

Fig. 1. Histogram of image *Phobos*: original image (left) and negative (right).

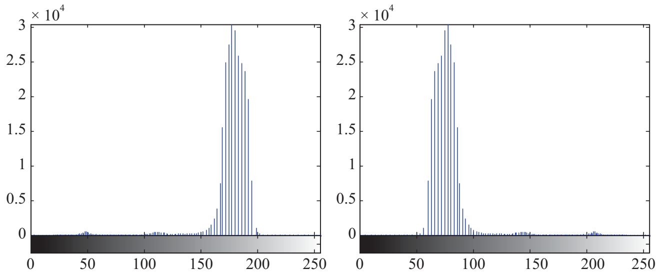

Fig. 2. Histogram of image *Aircraft*: original image (left) and negative (right).

III. EXPERIMENTAL RESULTS AND DISCUSSION

GLG was confirmed to be an automatic and effective method through exemplification using several low-contrast images with particularly high histogram components on the leftmost side. In addition, we sought to determine whether the method was effective in other low-contrast images. In this section, we present two images, *Phobos* and *Aircraft*, in two versions each: original and negative. Each image exhibits unique histogram characteristics, and both serve to illustrate the efficacy of our improved GLG. The corresponding histograms of images *Phobos* and *Aircraft* are displayed in Figs. 1 and 2. The number of histogram support on *Phobos* has 256, and that on *Aircraft* has 139. The BGL of *Phobos* is at 0 (255 for negative) and that of *Aircraft* is at 177 (78).

One of the objectives of using the negatives was to produce an image with a particularly high histogram component on the rightmost side, and then we use the newly produced image to test the performance of contrast enhancement. Another

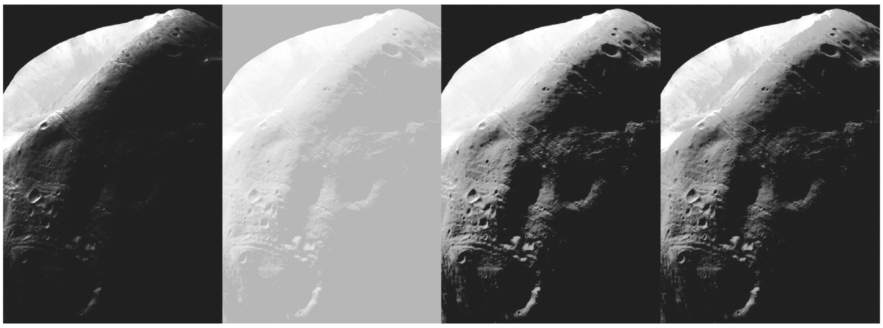

Fig. 3. Contrast enhancement for image *Phobos* from left to right: original image, HE, GLG, and improved GLG with threshold 12.

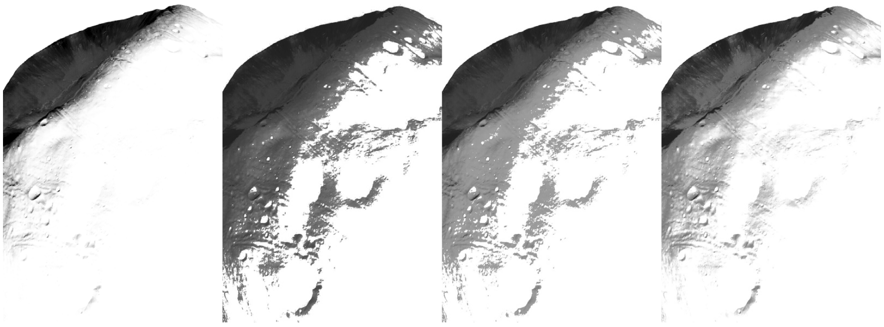

Fig. 4. Contrast enhancement for the negative of image *Phobos* from left to right: original image, HE, GLG, and improved GLG with threshold 12.

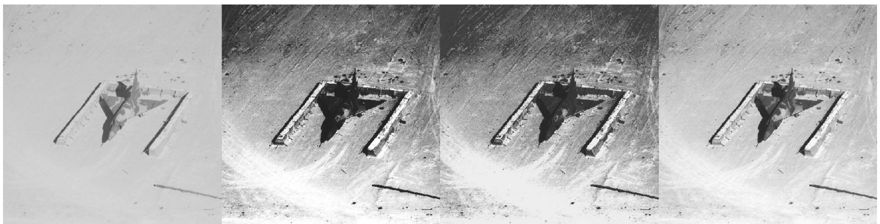

Fig. 5. Contrast enhancement for image *Aircraft* from left to right: original image, HE, GLG, and improved GLG with threshold 12.

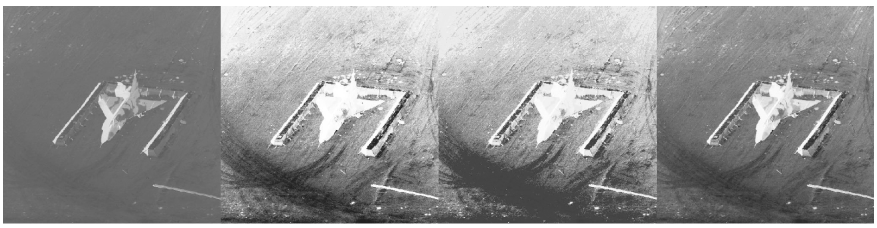

Fig. 6. Contrast enhancement for the negative of image *Aircraft* from left to right: original image, HE, GLG, and improved GLG with threshold 12.

objective was to determine whether GLG was affected by inverse implementation. The image *Aircraft* was used to test the outcome in general low-contrast images under contrast enhancement; in the image, several relatively high histogram components were distributed in the histogram. These four images sufficed to verify that the original GLG exhibited limitations in its implementation, and confirmed that our improved GLG could be applied to various low-contrast images. The corresponding contrast-enhanced images for *Phobos* are displayed in Figs. 3 and 4, and those for *Aircraft* are displayed in Figs. 5 and 6. Table 1 displays five measures for *Phobos*, enabling a quantitative comparison of the image enhanced by improved GLG with three other images (the original image and images enhanced by HE and GLG); Table 2 displays five measures for *Aircraft*.

These five standard measures comprised the mean, AIC, BGL, AD [6], and SD [7]. The mean provided a criterion to determine whether the average of the enhanced image was

Table 1. Comparison of methods for *Phobos*.

	Mean	AIC	BGL	AD	SD
image	31.73	3.51	0	26.70	69.32
HE	176.23	3.20	157	14.16	29.63
GLG	53.25	**3.31**	0	**39.59**	**83.83**
GLG*	**47.27**	**3.31**	0	35.67	76.62

* Improved version of GLG with a threshold of 12.

Table 2. Comparison of methods for the negative of *Phobos*.

	Mean	AIC	BGL	AD	SD
image	223.27	3.51	255	26.70	69.32
HE	176.55	3.20	**255**	**50.92**	**101.33**
GLG	195.24	3.05	**255**	41.99	86.20
GLG*	**207.68**	**3.31**	**255**	35.72	76.73

* Improved version of GLG with a threshold of 12.

Table 3. Comparison of methods for *Aircraft*.

	Mean	AIC	BGL	AD	SD
image	175.33	4.00	177	8.50	22.12
HE	138.24	3.88	126	**42.99**	**74.88**
GLG	129.18	3.73	113	41.33	72.23
GLG*	**175.14**	**3.95**	**174**	24.62	46.58

* Improved version of GLG with a threshold of 12.

Table 4. Comparison of methods for the negative of *Aircraft*.

	Mean	AIC	BGL	AD	SD
image	79.67	4.00	78	8.50	22.12
HE	138.31	3.88	159	**41.44**	**72.19**
GLG	133.91	3.62	33	40.17	70.58
GLG*	**90.80**	**3.95**	**93**	24.11	45.01

* Improved version of GLG with a threshold of 12.

close to that of the original image. Its equivalence is called the AMBE, which is a crucial criterion for application in consumer electronics. The AIC enabled measuring the average information of an image; the higher the value of AIC was, the more details an image exhibited. The BGL enabled determining whether the principal gray level was shifted excessively, particularly for images with high histogram components on the leftmost and rightmost sides. The AD and SD were used to measure contrast values; the higher the AD or SD was, the higher the contrast was.

The image *Phobos* is a classic example of a low-contrast image, and has been used often in previous studies. The overall performance of the original GLG, including two objective contrast measures and visual effects, was superior to those of HE and HS. Table 1 shows that GLG yielded the sharpest contrast and its visual effects were considerable; however, Fig. 3 demonstrates that our improved GLG led to clearer visual effects in the top left corner of the object. Moreover, the mean of the improved version was the closest to that of the original image.

For the negative of *Phobos*, Table 2 shows that HE led to the sharpest contrast, and GLG yielded the second-largest amount; nevertheless, Fig. 4 shows that images for which HE or GLG was used seem like a painting with the paint flaking off; by contrast, the image for which our improved GLG was used exhibits a distinct and satisfying appearance. In addition to detailing visual effects, Table 2 demonstrates that the overall performance of our improved GLG was superior. The mean of the improved version was the closest to the original image, the AIC value was the highest, and the contrast was increased to 1.34 times that of AD and 1.11 times that of SD.

The histogram of the image *Aircraft* is another classic image with low contrast that has been widely used in previous studies, for example [8]. Figs. 5 and 6 reveal that our improved GLG led to superior visual effects. Tables 3 and 4 also demonstrate that our improved GLG was superior to HE and the original GLG, only sacrificing a little contrast; the mean, AIC, and BGL were closest to the original image, but the improved GLG still increased the contrast to 2.87 times that of AD and 2.07 times that of SD, on average.

IV. CONCLUSION

GLG is an automatic and effective contrast-enhancement technique. It was proposed to increase the contrast of an image to a maximum through recombining histogram components of an image. It performs satisfactorily for low-contrast images with a particularly high histogram component on the leftmost side, but fails in cases where a particularly high histogram component is on the rightmost side, and in cases where several high histogram components are exhibited in the histogram.

To extend applications of GLG to other low-contrast images, we identified its limitations in the procedure of recombination. A pivotal factor is that GLG easily causes the spacing between histogram components to be wide to the extent that the visual effects of an enhanced image is destroyed. We discovered that an additional constraint in selecting an optimal transformation function facilitated identifying the most appropriate transformation function while taking visual effects into consideration.

In this study, two classic images were used to confirm that our improved GLG effectively preserved a favorable appearance at the cost of inferior contrast. These two images were unique and our improved GLG performed satisfactorily in both images; this implies that our improved GLG can be used in a wide range of images.

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