IMAGE ENHANCEMENT USING SORTED HISTOGRAM SPECIFICATION AND POCS POSTPROCESSING

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ABSTRACT

An image enhancement algorithm based on the sorted histogram equalization (SHE) and specification (SHS) is proposed in this work. Although SHE and SHS can generate an arbitrary output histogram exactly, they yield false contour artifacts and amplify noises in many cases. To reduce these artifacts, we propose a postprocessing scheme using the projection onto convex sets (POCS) theory. Specifically, the proposed algorithm iteratively processes the output images of SHE and SHS using the low-pass, boundary and dithering conditions. Simulation results demonstrate that the proposed algorithm provides an excellent image quality, by improving the contrast while reducing undesired artifacts.

Index Terms— histogram equalization, histogram specification, POCS, and image enhancement.

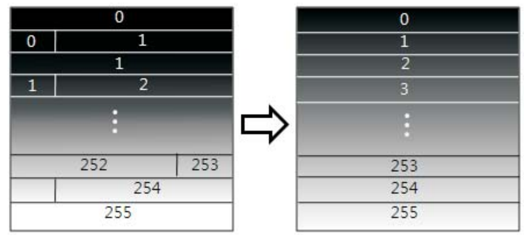
1. INTRODUCTION

Histogram equalization is a classical approach to contrast enhancement [1]. It attempts to make the histogram of an input image as uniform as possible, and thus increases the dynamic ranges of low-contrast images adaptively. It is widely used in various applications for its effectiveness and simple implementational complexity.

A variety of histogram equalization techniques have been proposed. According to whether the equalization is locally adaptive or not, these techniques can be classified into local histogram equalization and global histogram equalization. Local histogram equalization can extract small details more effectively, but it may break the ordering of pixel values, which is not desirable in some applications. Also, as in [2], the histogram can be first divided into partitions, and then each partition can be separately equalized. However, all these techniques simply stretch or compress the input histogram using a transfer function. Therefore, the output histogram does not have the ideal uniform distribution in most cases. Also, the output image may contain artifacts, such as false contours and amplified noises, due to the over-stretching of the histogram.

The ideal uniform distribution can be achieved based on the sorting of input pixel values [3, 4, 5]. After sorting, the pixels are assigned output values in the ascending order such that the output histogram is perfectly uniform. When an input value should be mapped to multiple output values, the order of the pixels are determined randomly or based the average values of neighboring pixels.

The proposed algorithm also uses the sorted histogram equalization (SHE) and specification (SHS), as in [3, 4, 5]. In addition to achieving the perfectly uniform histogram for contrast enhancement, SHE also provides additional information, called boundary values. Using the information, the proposed algorithm further processes the equalized output to improve the image quality. Specifically, we use a postprocessing technique based on the theory of projection onto convex sets (POCS). Simulation results demonstrate the proposed algorithm effectively enhances the contrast of low-contrast images, while reducing undesired artifacts.



(a)

Original Value	Mapping Value	Lower bound	Upper bound
0	0~1	0	1
1	1~3	1	3
2	3	3	3
⋮			
253	253~254	253	254
254	254	254	254
255	255	255	255

(b)

Fig. 1. Illustration of SHE: (a) the mapping of pixel values and (b) the table for boundary conditions.

The rest of this paper is organized as follows. Section 2 describes SHE and SHS, and Section 3 proposes the POCS postprocessing scheme. Section 4 presents experimental results. Finally, concluding remarks are given in Section 5.

2. SORTED HISTOGRAM EQUALIZATION AND SPECIFICATION

In this section, we briefly describe the SHE and SHS algorithms [3, 4, 5], which can generate the desired output histogram exactly. SHE is the special case of SHS when the desired histogram is a uniform distribution.

In SHE, we first push the location and value of each pixel in the input image into a list. Next, according to the pixel values, we sort the list in the ascending order. We then compute the mapping

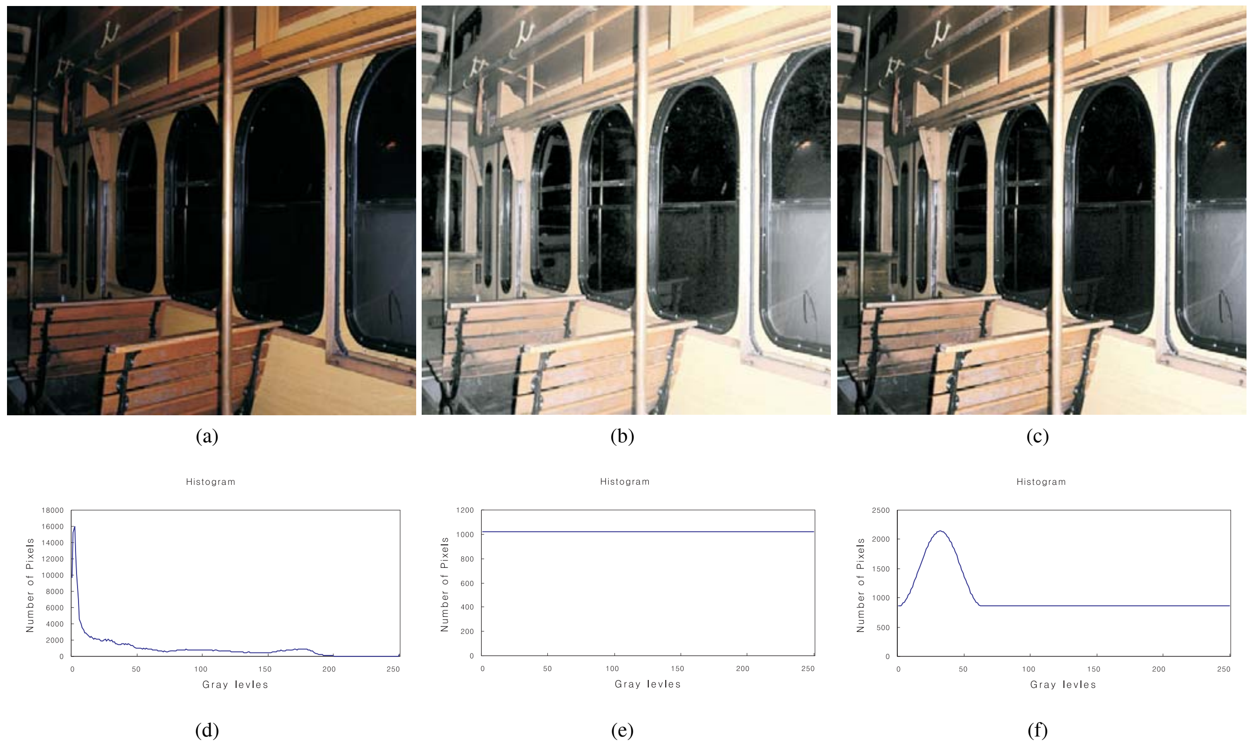


Fig. 2. SHE and SHS: (a) original image, (b) output of SHE, and (c) output of SHS. (d), (e), and (f) are the histograms of (a), (b), and (c), respectively.

parameter

$$S = \frac{\text{number of pixels in input image}}{\text{dynamic range}}. \quad (1)$$

For example, if the image resolution is 512×512 and gray levels range from 0 to 255, the mapping parameter S is 1,024. Then, as shown in Fig. 1 (a), the first S pixels are mapped to gray level 0, the next S pixels are mapped to gray level 1, and so on.

In some cases, we should assign different output gray levels to the pixels of the same input gray level. In Fig. 1 (a), the input level 1 is mapped to three output levels from 1 to 3. In such a case, we use a tie-breaking rule, which further sorts the pixels based on the second attributes. In this work, the average of 8 neighboring pixel values is used as the second attribute.

In a similar way, SHS can generate an arbitrary output histogram. Let $h(n)$ denote the number of pixels with gray level n, specified by the output histogram. After sorting the input pixels, SHS maps the first $h(0)$ to gray level 0, the next $h(1)$ pixels to gray level 1, and so on. In other words, instead of using the fixed mapping parameter S in (1), SHS employs the specified output histogram.

Fig. 2 shows that results of SHE and SHS. The original image in Fig. 2 (a) is too dark overall. After the equalization, SHE provides a higher contrast in Fig. 2 (b), and its histogram in Fig. 2 (e) is perfectly uniform. However, SHE overstretches the contrast, and thus the inside of the train looks unnatural. As shown in Figs. 2 (c) and (f), SHS puts a raised cosine window in the dark region, and provides a more natural output image.

3. POSTPROCESSING BASED ON POCS

Although SHE and SHS have an excellent capability of contrast enhancement, they can bring out undesirable artifacts, such as false contours and amplified noises. Fig. 3 (b) shows an example of SHE outputs. The details of the dark background in the original image are enhanced efficiently, but annoying false contours are also generated by SHE as shown in the magnified image in Fig. 3 (e). To alleviate these artifacts, we can employ a low-pass filter. But, the low-pass filtering inevitably causes the blurring of edge information, which degrades the image quality.

To reduce noises without causing blurring, we propose a post-processing algorithm based on the POCS theory. In POCS, the desired properties of output images are represented by convex sets. By projecting an input image iteratively over those convex sets, it converges to the final image with the desired properties [6, 7]. In this work, we use the following convex conditions.

- Low-pass condition:

  First, the image should contain only low frequency components. This is because neighboring pixel values in real images are similar to each other in most cases. In this work, we use the 3×3 block filter as the low-pass filter.

- Boundary condition:

  The next convex set is defined by the boundary condition. The low-pass filter changes the output image of SHE to make the image smoother. On the other hand, the boundary condition constrains the image to be close to the output of SHE. To this end, we use the lower and upper bounds of the SHE mapping. For example, in Fig. 1 (b), the pixels with the original value

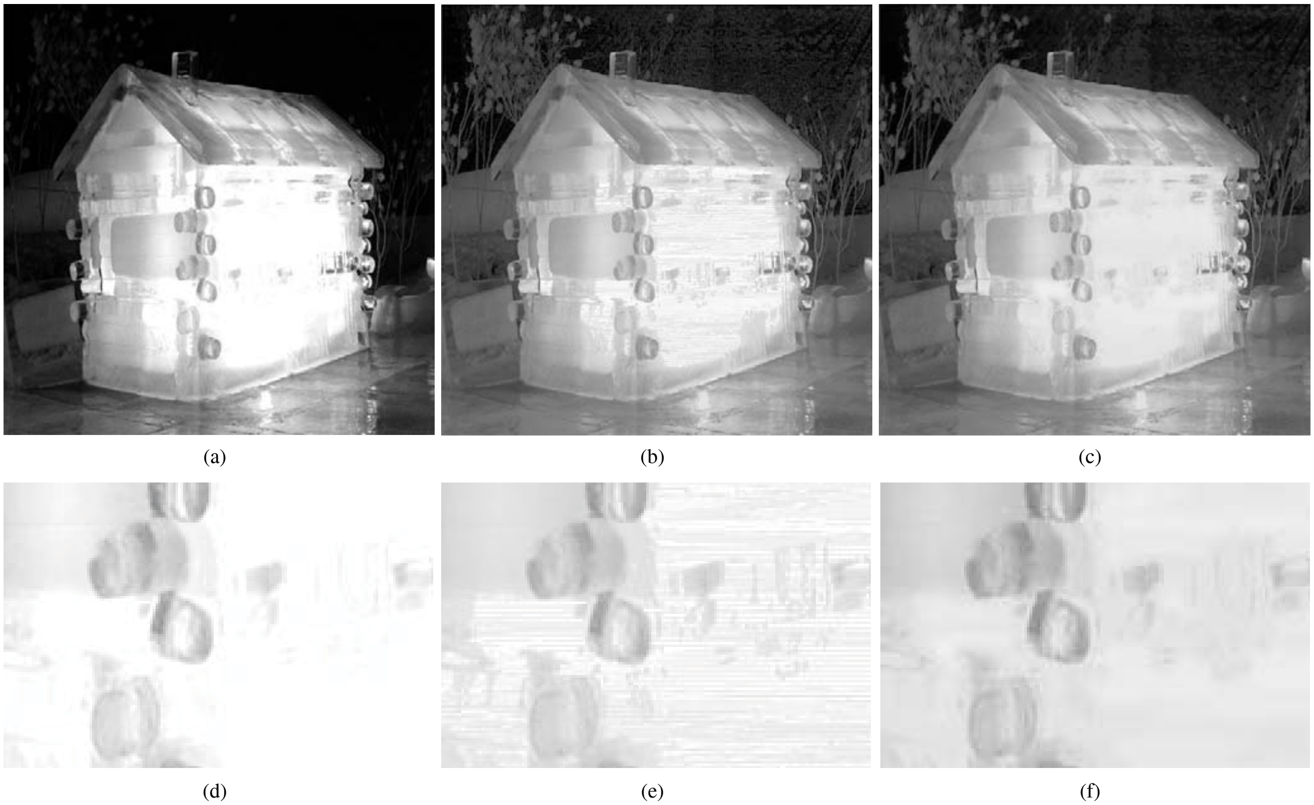


Fig. 3. (a) Original image, (b) output of SHE, and (c) output of SHE + POCS. (d), (e), and (f) are enlarged parts of (a), (b), and (c), respectively.

1 are mapped by SHE to output values from 1 to 3. Thus, the lower bound is 1 and the upper bound is 3. Therefore, if the value of such a pixel is changed to be lower than 1 or greater than 3 by the low-pass filter, the value is changed back to 1 or 3, respectively.

In other words, the upper bound and the lower bound of a pixel represent the range, within which the value can vary freely. Note that in SHE a specific value is selected within the range using the second attribute. However, when the low-pass filter is applied, the value can move outside the range. The boundary condition recovers such a value to the upper bound or the lower bound, and thus the value belongs to the range again.

The low-pass condition and the boundary condition define convex sets, respectively. We employ an additional condition, called dithering.

- Dithering:

  To reduce contouring artifacts in the quantization, a small pseudorandom noise, called dither, can be added before quantization and subtracted after quantization [8]. Similarly, SHE or SHS often generates false contours when stretching or compressing the histogram. Thus, we also add a pseudorandom noise, which is uniformly distributed in $[-13, 13]$, to each pixel to suppress the contours.

Unlike the low-pass condition and the boundary condition, the dithering condition does not define a convex set.

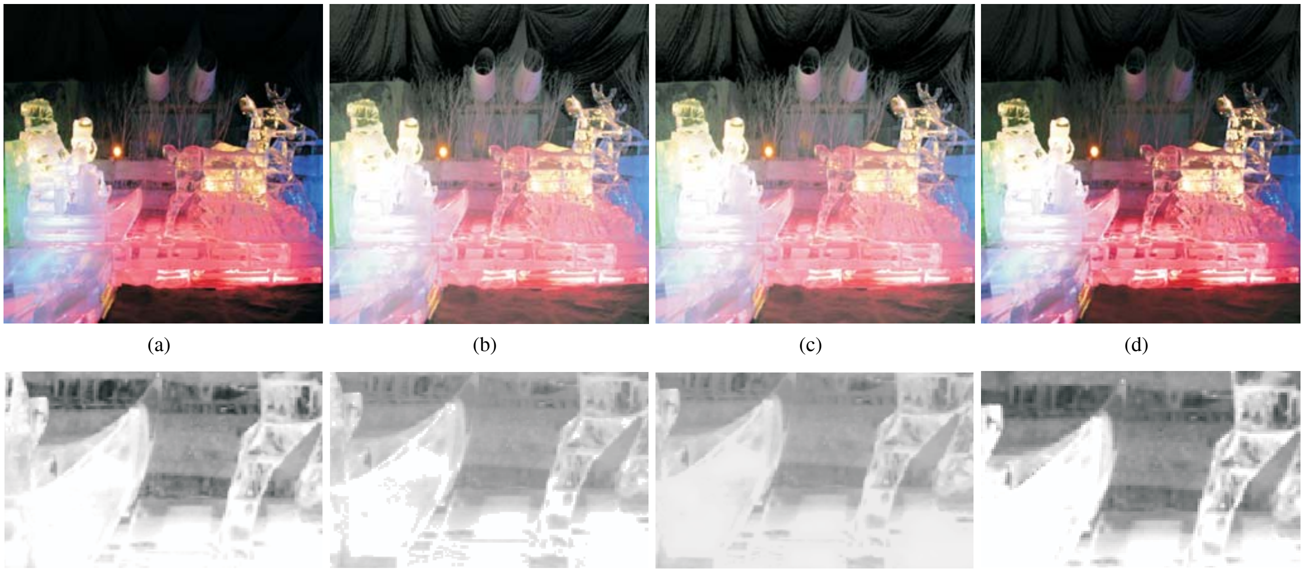
The low-pass, boundary, and dithering conditions are iteratively applied, until the difference between two successive iterations becomes negligible. Since the dithering is not a convex condition, it is not guaranteed that the overall iterative procedure converges. However, extensive simulation results confirm that the proposed algorithm converges in about 10 iterations in most cases. This is because the boundary condition constrains the image to be close to the SHE output, even though the other two conditions changes the image to be smoother with less false contours.

Figs. 3 (c) and (f) shows the results of the proposed algorithm. As compared with Figs. 3 (b) and (e), which are processed with SHE only, the proposed algorithm effectively reduces false contours and provides a more natural image.

4. EXPERIMENTAL RESULTS

The performance of the proposed algorithm was evaluated on various images of size 512×512. The test was performed using a computer with a Pentium IV 3Ghz processor and 1 Gbyte RAM. Only the luminance component was processed, while the chrominance component was kept unchanged. The proposed algorithm took about 0.2$\sim$0.3s to process each image.

While the SHE algorithm is fully automatic, the SHS algorithm requires user interactions to define the shape of the desired output histogram. In this work, we constrain the histogram to be a raised cosine window over a flat curve, as shown in Fig. 2 (f). We designed an interface, which allowed a user to change the center, width and height of the raised cosine window and see the output image interac-



(a) (b) (c) (d)

(e) (f) (g) (h)

Fig. 4. Comparison of the proposed algorithm with the conventional histogram equalization method in [1]: (a) the original image SANTA, (b) the conventional histogram equalization method, (c) the proposed SHE + POCS algorithm, and (d) the proposed SHS + POCS algorithm. (e), (f), (g), and (h) are enlarged parts of (a), (b), (c), and (d), respectively.

tively.

Fig. 4 (a) is the “SANTA” image, which is a low-contrast, low-key image. Since the background is dominated by dark pixels, it is hardly visible. Figs. 4 (b), (c), and (d) show the output images, acquired by the conventional histogram equalization method in [1], the proposed SHE + POCS algorithm, and the proposed SHS + POCS algorithm, respectively. The conventional histogram equalization method also brings out the details in the background, but it causes false contour artifacts in the foreground, as shown in the enlarged image of Fig. 4 (f). On the other hand, the proposed algorithm reduces those artifacts efficiently in Fig. 4 (g). Also, by using the proposed SHS algorithm, the colors around the dears are made more vivid and natural, as shown in Fig. 4 (d).

5. CONCLUSION

In this work, we proposed an image enhancement algorithm based on SHE and SHS, which can make an arbitrary output histogram exactly. However, SHE and SHS often yield false contour artifacts and amplify noises. To reduce these artifacts, we proposed a postprocessing scheme using the POCS theory. Specifically, the proposed algorithm employs the low-pass, boundary and dithering conditions iteratively to enhance the quality of output images. Simulation results demonstrated that the proposed algorithm has an excellent capability of image enhancement.

6. ACKNOWLEDGEMENTS

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