Automatic Contrast Enhancement using Reversible Data Hiding

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***Abstract*—Automatic image enhancement is increasingly becoming a popular tool for the smartphone environment. The tool automatically enhances the image right after it has been stored to enhance user's experience. But, because enhancements are subjective and dependent on the image, the original image is backed up to provide a recovery option. This requirement inevitably increases the storage requirement. In order to reduce it, a novel automatic contrast enhancement based on reversible data hiding (ACERDH) is proposed. The proposed method mimics the equalization effect observed in the basic contrast enhancement technique called global histogram equalization, while providing reversibility. The experiment visually show improved contrast. Additional experiment was done to compare the embedding capacity with an another reversible data hiding based contrast enhancement technique [1]. The proposed method is fit for automation, while providing data hiding capability and removing the additional storage requirement.**

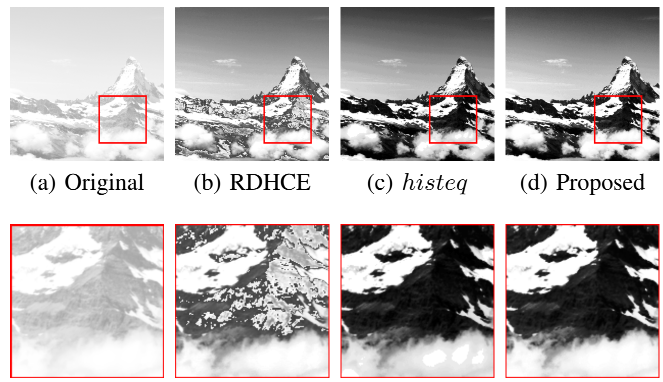
I. Introduction

Global histogram equalization (GHE) is a basic contrast enhancement technique which is widely used in digital forensic investigations, medical image analyses, and scientific visualization [2]. It is used to emphasize image details that are not clearly visible to the human eyes. In the literature, well-known methods are based on histogram equalization techniques found in the methods developed by Kim [3] and Stark [4], each of which attempts to provide a natural enhancement. Common equalization techniques have been irreversible.

Recent advancement of smartphones allowed wide adaption of a tool called automatic image enhancement. The original image is always kept as a backup because the enhancements are subjective and the user may prefer the original or wants to apply a different enhancement.

In the past, Wu *et al.* [1] introduced a contrast enhancement technique using a reversible data hiding technique based on the method by Ni *et al.* [5]. In this method, because the data hiding operation is reversible, the original image doesn't need to be kept separately. Hereafter, this data hiding method is referred to as RDHCE.

Before RDHCE is proposed, reversible data hiding was originally used for authentication purposes for distortion sensitive applications. Reversible data hiding or watermarking techniques embed data in a host signal like an image [5] such that the original image and the data can both be recovered in a lossless manner. Data hiding inevitably introduces distortion to the image. Therefore, most implementations aim to maximize the embedding capacity while keeping the distortion at a minimum.



(a) Original (b) RDHCE (c) $histeq$ (d) Proposed

(e) Close up (f) Close up (g) Close up (h) Close up

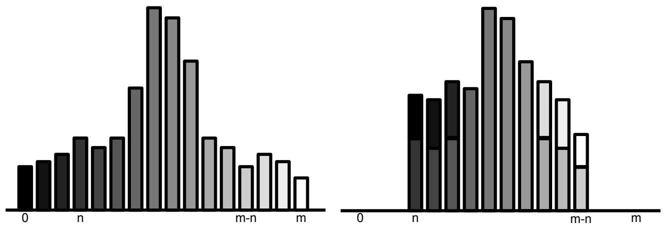
Fig. 1: Close ups of the over exposed image ”Matterhorn”[6]. The image enhanced with RDHCE (with 64 repetitions of histogram shifting) has horrible artifacts and looks unnatural. $histeq$ is a well known global histogram equalization function in Matlab

On the contrary, RDHCE uses distortion to equalize the histogram. Data hiding is implemented in the two highest peaks of the pixel histogram. The two peaks are shifted toward the boundary bins, while the bins in between are not modified. With multiple repetitions, the equalization effect is amplified and results in an equalized histogram. It achieves a good contrast enhancement for images not using the full intensity spectrum.

However, for poorly exposed images, the algorithm can produce intensity mismatched artifacts as shown in Fig. 1(b) and (f), making it not suitable candidate for automatic contrast enhancement. This property will be discussed in depth in Section II. The contributions of this paper are as follows:

1) An automatic contrast enhancement using reversible data hiding (ACERDH) which removes the additional space requirement is proposed.
2) The algorithm enhances poorly (under or over) exposed images without introducing intensity mismatched artifacts just like GHE.

The rest of this paper is organized as follows. Section II discusses the limitation of RDHCE. Section III presents the



(a) (b)

Fig. 2: Preprocessing effect on the histogram: ($n = 3$), histogram (a) before and (b) after preprocessing

details of the proposed algorithm. Section IV describes the experimental results. Finally, some concluding remarks are given in section V.

II. Limitations of the RDHCE method

Although it is not discussed in their original paper, RDHCE [1] has certain limitations in handling pixels close to the intensity boundaries. The preprocessing step which is needed to prevent overflow and underflow problem can create undesirable artifacts as shown in Fig. 1(b) and (f). These will be referred as intensity mismatched artifacts.

The following example will demonstrate how intensity mismatched artifacts are produced: As mentioned in the introduction, embedding uses one pair of peaks for each repetition and preprocessing is applied before embedding. Suppose that embedding is done n times. Then, $2n$ boundary pixels are combined on each side to make room for the embedding, as shown in Fig 2. For the lower border, bins $[0, n-1]$ are combined with bins $[n, 2n-1]$. Bin $n-1$ is combined with $2n-1$, $n-2$ with $2n-2$, and so on until 0 is combined with n. Bins $n-1$ and n which were originally neighbors are now far apart from each other in bins $2n-1$ and n. Like this, preprocessing can result in pixels with mismatched intensity values. This will be defined as intensity mismatched artifacts.

The effect is hardly visible if n is small or when few pixels are affected. However, strong artifacts are visible for a large n and for images with a large amount of pixels in the affected area. The artifacts can become more prominent after the embedding. If the highest peaks are within the area affected by the preprocessing, some of the preprocessed pixels can be shifted further away from its original neighbors from embedding, which results in the brightened rocks shown in Fig. 1(f). In the proposed algorithm, the preprocessing step is eliminated to prevent such artifacts from showing up.

III. Proposed Algorithm: ACERDH

Equalization and embedding are done in multiple repetitions. Each repetition shifts the pixels from the highest bin toward the lowest bin. In the end, the larger bins spread out over multiple bins, and the smaller bins become compressed. Unlike the previous work, a new location map is generated during each repetition. The embedding is repeated n times until the stop condition is met. Each repetition is realized through three sub-steps. The first step shown in Section III-A defines

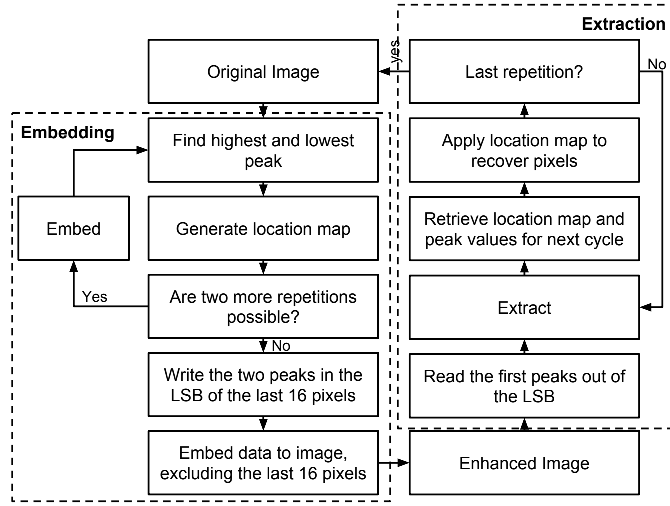


Fig. 3: Procedure of the proposed algorithm

the direction of the shifting. The second step is described in Section III-B and defines the unidirectional histogram shifting. The last step in Section III-C and describes the location map generation. The number of repetitions is determined using the stop condition described in Section III-D. The recovery process is discussed in Section III-E. The overview of the embedding and recovery procedures are outlined in Fig.3.

A. Shifting Direction

The histogram of the image is used to identify the two peaks required for the data embedding. Let P_H be the bin (or the peak) containing the highest number of pixels, whereas P_L be the bin containing the lowest number. The shifting direction value d in Equation (1) defines whether the histogram shift will be in the positive ($d = 1$) or negative ($d = -1$) direction.

$$d = \begin{cases} 1 & \text{if } P_L > P_H \\ -1 & \text{if } P_L < P_H \end{cases} \tag{1}$$

d is evaluated for every repetition to ensure smooth equalization.

B. Unidirectional Histogram Shifting

Let $b_k \in \{0, 1\}$ the bit to be embedded. For each pixel p, the watermarked pixel p' is obtained using Equation (2):

$$p' = \begin{cases} p + d \cdot b_k & \text{if } p = P_H \\ p + d & \text{if } min(P_H, P_L) < p < max(P_H, P_L) \\ p & \text{else} \end{cases} \tag{2}$$

The pixel values equal to P_H are embedded, the values strictly between P_H and P_L are shifted by d, and the rest are not modified. Notice that this will combine the bin $P_L - d$ with bin P_L, making it impossible to split them back again during the recovery. The location map is used to solve the problem.

C. Concurrent Location Map

The histogram shift combines bins P_L and $P_L - d$ into P_L. Therefore, a location map is needed to differentiate the combined bins. A novel method called "concurrent location map generation" is used. Unlike RDHCE, where the location map is generated just once, the proposed method generates one for every repetition. This is done to eliminate the intensity mismatched artifacts. All pixels in bin P_L are marked with 0 whereas the pixels in bin $P_L - d$ are marked with 1 as shown in Equation (3), where index i marks the relative position when raster scanning is used. This is further compressed using arithmetic coding.

$$l_i = \begin{cases} 0 & \text{if } p = P_L \\ 1 & \text{if } p = P_L - d \end{cases} \tag{3}$$

In addition to the location map, its size, the payload size, a stop flag (indicating whether the current repetition is the first) and pixel values P_H and P_L are appended at the beginning of the payload. During the recovery step, pixel values P_H and P_L can be read from the payload, but this is not possible for the recovery of the last embedding repetition as there is no payload. Instead, the final P_H and P_L are stored in the least significant bits (LSBs) of the last 16 pixels. Consequently those 16 pixels should be excluded from embedding in the very last repetition.

D. Stop Condition

The target is to run as many repetitions as possible to achieve the most equalized histogram. The lowest peak and location map size increase for every repetition. Simultaneously, the embedding capacity decreases. The algorithm is therefore stopped when the embedding capacity is not sufficiently large for the overhead information. The algorithm always computes the peaks P_H and P_L one step in advance to evaluate whether the current repetition is the second-to-last repetition.

E. Recovery

As with shifting, the recovery is also done one step at a time. For the first iteration of the recovery step, P_H and P_L is read from the LSBs of the last 16 pixels. Data can be extracted using Equation (4), whereas the image is recovered with Equation (5)

$$b_k = \begin{cases} 0 & \text{if } p' = P_H \\ 1 & \text{if } p' = P_H + d \end{cases} \tag{4}$$

$$p = \begin{cases} p' - d & \text{if } min(P_H, P_L) < p' < max(P_H, P_L) \\ p' & \text{else} \end{cases} \tag{5}$$

For perfect recovery, it is necessary to recover the bin $P_L - d$ from the bin P_L. This is done using the location map l with Equation (6).

$$p = \begin{cases} P_L & \text{if } p = P_L \text{ and } l_i = 0 \\ P_L - d & \text{if } p = P_L \text{ and } l_i = 1 \end{cases} \tag{6}$$

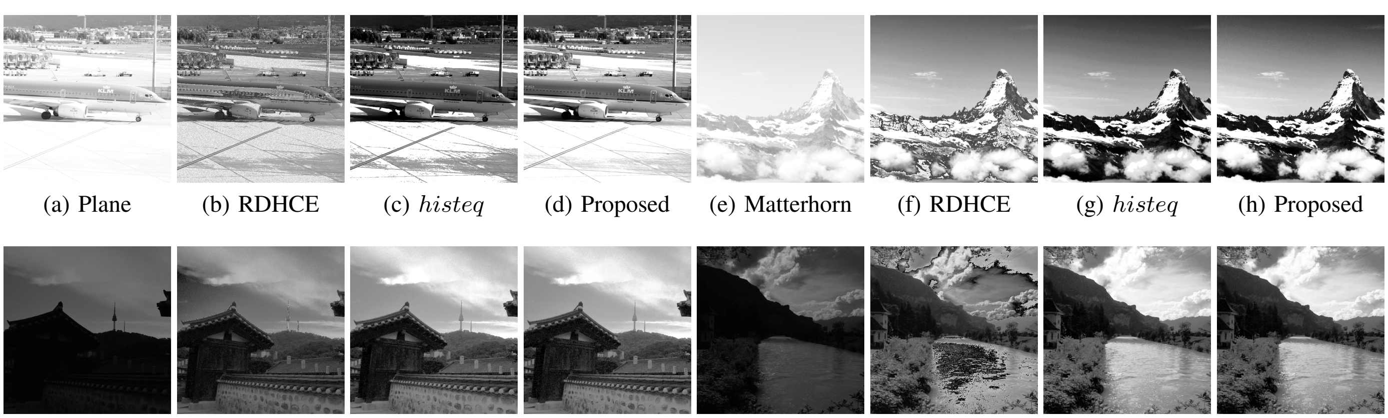
Bins P_H and P_L for the next repetition can be recovered from the payload. The resulting p from the Equation 5 is used as the new p' and the whole process is repeated until the stop flag is found in the payload.

IV. Experimental Results

The proposed method is compared with two other methods: RDHCE, and a global histogram equalization (GHE) technique from Matlab, called *histeq*. Experiments are conducted using two image data sets. The first set of images shown in Fig. 5, which are available online [6], are used for visual analysis. The set contains 4 under and over exposed images of size 512 by 512. The second set of images shown in Fig. 6, are widely used images from USC-SIPI data base. This set is used to compare the embedding capacity. The experiment results show that the proposed method improves the contrast while providing ability to hide data.

A. Visual Analysis

Fig 4 shows enhanced images of RDHCE, $histeq$ and the proposed method. The proposed method produces similar results to $histeq$, a well known technique without producing any of the intensity mismatched artifacts.



(a) Plane (b) RDHCE (c) $histeq$ (d) Proposed (e) Matterhorn (f) RDHCE (g) $histeq$ (h) Proposed

(i) Hanok (j) RDHCE (k) $histeq$ (l) Proposed (m) Creek (n) RDHCE (o) $histeq$ (p) Proposed

Fig. 4: Poorly exposed image data set enhanced with RDHCE (with maximum number of repetitions to produce most equalized images), $histeq$ and the proposed method.

(a) Plane (b) Matterhorn (c) Hanok (d) Creek

Fig. 5: Poorly exposed image data set [6]. (a) and (b) are over exposed, and (c) and (d) are under exposed.

(a) Lena (b) Boat (c) Barbara (d) F16

Fig. 6: USC SIPI image data set for distortion and embedding capacity comparison

Fig. 7 shows the image enhanced with RDHCE and the proposed method for different repetitions. The fully enhanced images are shown in Fig. 7(h) and 7(p). It can be observed that RDHCE images have the intensity mismatch artifacts for all the repetitions and the contrast becomes better with more repetition. On the other hand, the proposed method has no such artifacts and the contrast is much better than RDHCE.

Fig. 1 provides a closer look at the image "Matterhorn". Fig. 1(b), RDHCE image shows enhancements in certain parts but has many intensity mismatched artifacts. Fig. 1(g), $histeq$ image shows over enhancement artifacts, visible in the clouds and sky. The proposed algorithm result in much natural enhancement.

B. Embedding capacity

Fig. 9 compares the embedding capacity and peak signal to noise ratio (PSNR) between the proposed method and RDHCE. Each point represents the total embedding capacity and the PSNR for each repetition (or for a pair). A strange trend of the oscillating PSNR value can be observed for both methods. This effect is clearly evident for Barbara image for embedding capacity around 20,000 to 30,000: PSNR is increasing with the embedding capacity. This trend can be explained by understanding the nature of the multiple histogram shifting: Depending on the direction of the shift, histogram shifting may move some pixels to closer to its original value. The proposed method's embedding capacity is clearly lower than RDHCE, but it is visually more appealing as shown in Fig. 8.

V. Conclusion

A novel automatic contrast enhancement using reversible data hiding (ACERDH) is proposed. Unlike the previous work, intensity mismatched artifacts from preprocessing are entirely eliminated while enhancing the image. The proposed method provides an invertible alternative to the classical global histogram equalization. The proposed method provides good visual contrast, while removing the increased storage requirement of storing the original image.

Acknowledgement

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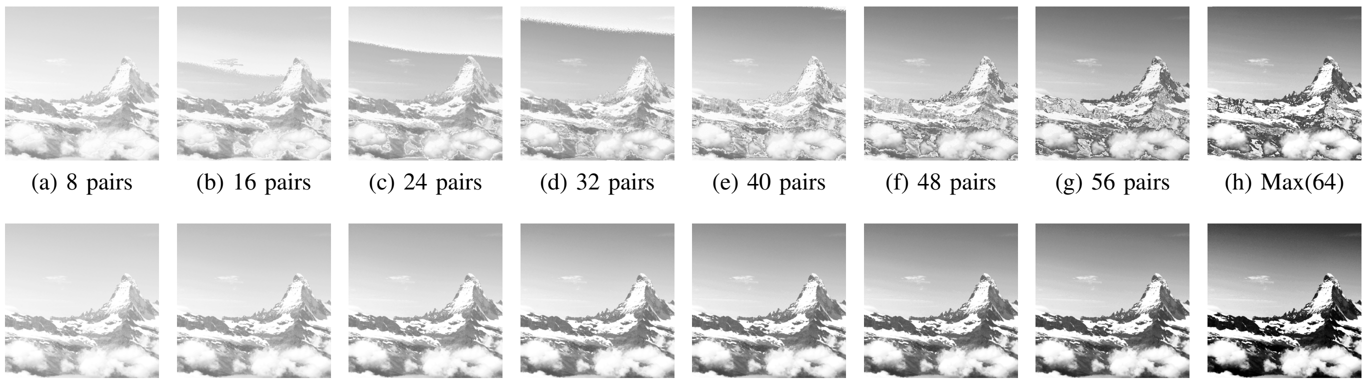
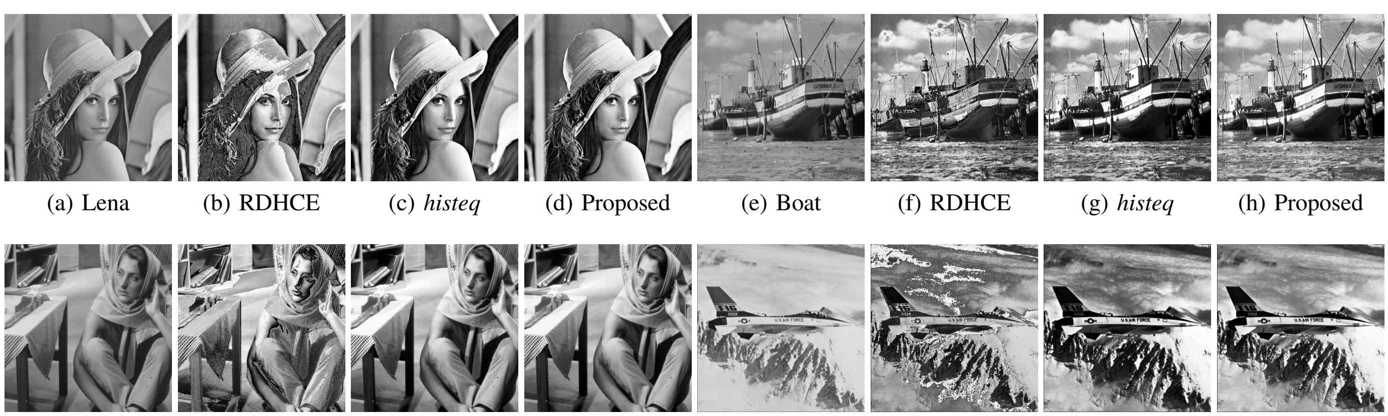


(a) 8 pairs (b) 16 pairs (c) 24 pairs (d) 32 pairs (e) 40 pairs (f) 48 pairs (g) 56 pairs (h) Max(64)

(i) 16 rep. (j) 32 rep. (k) 48 rep. (l) 64 rep. (m) 80 rep. (n) 96 rep. (o) 112 rep. (p) Max(169)

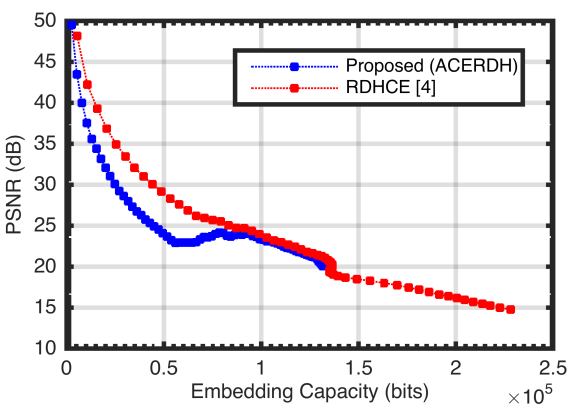
Fig. 7: Enhanced images with RDHCE ((a)-(h)) and the proposed method ((i)-(p)) with different numbers of pairs/repetitions. One pair of peaks used for embedding in RDHCE is equivalent to two repetitions in the proposed method.



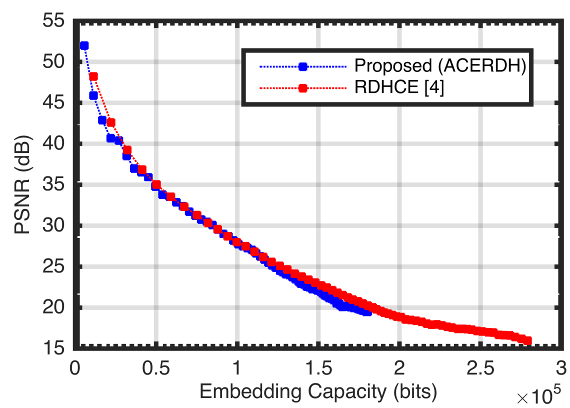
(a) Lena (b) RDHCE (c) *histeq* (d) Proposed (e) Boat (f) RDHCE (g) *histeq* (h) Proposed

(i) Barbara (j) RDHCE (k) *histeq* (l) Proposed (m) F16 (n) RDHCE (o) *histeq* (p) Proposed

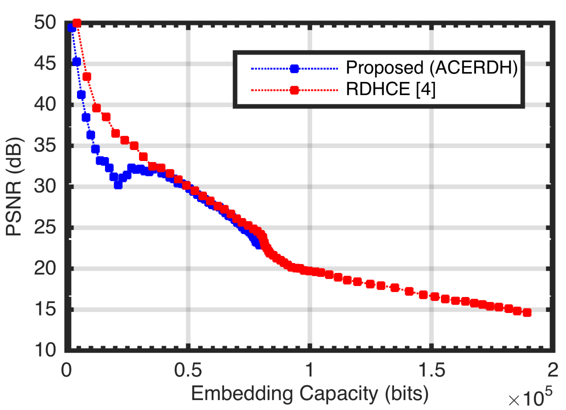
Fig. 8: USC-SIPI image data set enhanced with RDHCE (64 repetitions), *histeq*, and the proposed method.



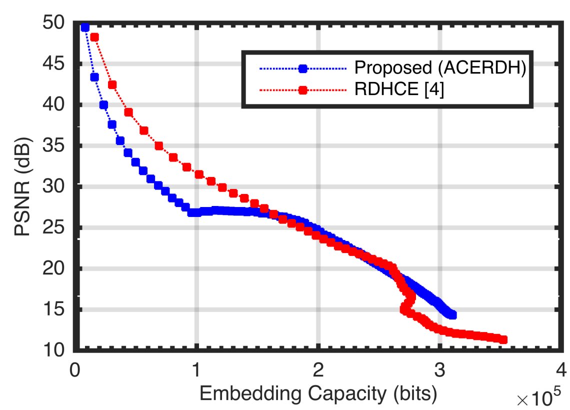
(a) Lena



(b) Boat



(c) Barbara



(d) Airplane

Fig. 9: Comparison of PSNR and embedding capacity for USC-SIPI image database