Automatic Contrast Enhancement using Reversible Data Hiding with Distortion Minimization

Suah Kim
Department of Information Security
Korea University
Seoul, South Korea
suahnkim@gmail.com

Hyoung Joong Kim
Department of Information Security
Korea University
Seoul, South Korea
khj-@korea.ac.kr

***Abstract*—Automatic contrast enhancement using reversible data hiding (ACERDH) has been found to be useful in automatic image enhancement field. Instead of just providing data hiding ability, ACERDH also equalizes the pixel histogram as a part of data hiding process. This allows original image recovery directly from the enhanced image, without any additional data, which provides file saving feature by not having to save the original image. In this paper, we propose two improvements and two novel distortion minimization methods for ACERDH [1] method. The experimental results show that the proposed method has higher embedding capacity and lower distortion than ACERDH.**

***Index Terms*—Automatic contrast enhancement, reversible data hiding, distortion minimization**

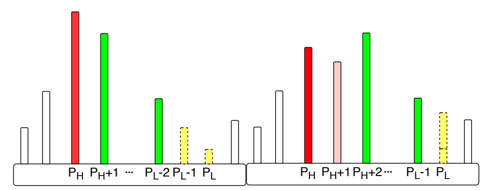
I. Introduction

Automatic contrast enhancement using reversible data hiding (ACERDH) [1] provides file saving feature for automatic image enhancement (AIE) applications. AIE is a popular tool in mobile environment, where

- Image is enhanced without user's inputs so that the user does not need to learn different enhancement tools and techniques.
- Original image recovery is possible at any time, in case the user is not satisfied with the enhanced image or if they need the original image.

However, to support original image recovery, there is an increase in file storage requirement from having to keep original image as a backup. This increase in file storage requirement can be removed if ACERDH is used, because the original image can be recovered from the enhanced (watermarked) image without any additional data.

ACERDH is based on the principal of global histogram equalization [2]. The original paper which suggests using reversible data hiding to achieve histogram equalization is by Wu et al. [3]. They showed that applying histogram shifting to pixel histogram in repetitions will slowly spread histogram bins more towards the boundary bins, creating a histogram equalization effect. However, it was not suitable for AIE; to produce an enhanced image with good contrast, number of repetitions had to be applied manually with visual inspection to ensure that there is no intensity mismatch artifacts [1]. ACERDH is a novel reversible data hiding method to eliminate the intensity mismatch artifacts and the need for visual inspection, so that it is suitable for AIE applications.



(a) Before (b) After

Fig. 1: Example of unidirectional histogram shifting

In this paper, we extend the work done by Kim et al. [1] in three ways. First, an improved bin selection is proposed to eliminate early termination. Second, an improved stop condition is proposed. Third, instead of focusing only on maximizing embedding capacity and the equalization of the pixel histogram, we propose two novel distortion minimization techniques.

II. Related Work: ACERDH

ACERDH, also known as automatic contrast enhancement using reversible data hiding, enhances the image using uni-directional histogram shifting. Uni-directional histogram shifting is applied to pixels in repetitions, such that the resulting pixel histogram becomes equalized compared to the original pixel histogram.

A. Uni-directional histogram shifting

Uni-directional histogram shifting spreads the highest peak (P_H) and combines the lowest peak (P_L) with its neighbor ($P_L - d$), where d represents the direction:

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

This is not the final published version, it is an accepted version of the paper. This work was supported by the National Research Foundation of Korea grant funded by the Korea government (MEST) (No.NRF-2019R1I1A1A01059582) and supported by Institute for Information & communications Technology Promotion grant funded by the Korea government (MSIP) (No.2018-0-00365, Development of on-off hybrid blockchain technology for real-time large-scale data distribution).

Uni-directional histogram shifting is formally defined as follows:

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

p' represents the histogram shifted version of the pixel p, and $b_k \in \{0, 1\}$ is the embedding bit. Therefore, the number of pixels equal to P_H represents the embedding capacity.

An example of a uni-directional histogram shifting is shown in Fig. 1. The peak P_H is split between P_H and P_H+1, peaks between P_H+1 and P_L-2 are shifted by 1, and peak P_L-1 is combined with P_L.

To extract the embedded bits from the histogram shifted pixels:

$$b_k = \begin{cases} 0 & \text{if } p' = P_H \\ 1 & \text{if } p' = P_H + d \end{cases} \tag{3}$$

The histogram shifting process is reversed using the following:

$$p = \begin{cases} p' - d & \text{if } min(P_H, P_L) < p' < max(P_H, P_L) \\ p' & \text{else} \end{cases} \tag{4}$$

The location map (l) is used to split back the pixels valued P_L to P_L and $P_L - d$.

$$p = \begin{cases} P_L & \text{if } p = P_L \text{ and } l_i = 0 \\ P_L - d & \text{if } p = P_L \text{ and } l_i = 1 \end{cases} \tag{5}$$

where l is:

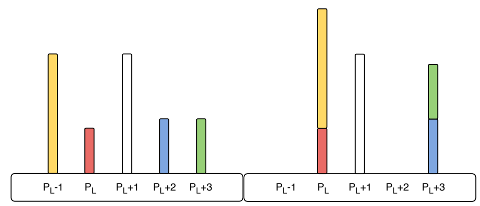
$$l_i = \begin{cases} 0 & \text{if } p = P_L \\ 1 & \text{if } p = P_L - d \end{cases} \tag{6}$$

Note that l is embedded as a side information during histogram shifting.

Uni-directional histogram shifting is repeated until the stop condition, the size of the side information is bigger than the embedding capacity, is reached. Detailed information about all the side information can be found in Ref. [1].

B. Limitation of ACERDH with location map minimization

P_H and P_L are selected to maximize embedding capacity and minimize the location map. Although selecting P_H as the most frequent pixel maximizes the embedding capacity, selecting P_L as the least frequent pixel does not produce the smallest possible location map. This is because the location map's size is dependent not only on P_L but also on $P_L - d$. An example is shown in Fig. 2, where ACERDH does not produces the smallest location map. The location map's size produced by ACERDH is equal to the number of pixels valued P_L and $P_L - 1$, which is bigger than the number of pixels valued $P_L + 2$ and $P_L + 3$.



(a) Before combined (b) Combined

Fig. 2: Limitation of ACERDH in location map minimization: Combining peaks $P_L + 2$ and $P_L + 3$, results in a smaller location map than combining peaks P_L and $P_L - 1$.

III. Proposed Improvement

A. Improved P_L Selection

In ACERDH, P_L is selected without any regards to the position of P_H. However, there are situations where certain peaks are not possible to be used as P_L, because there needs to be one peak ($P_L - d$) between peaks P_H and P_L.

For example, $P_H = 254$ and $P_L = 255$ is not possible. This is because bin $P_L - 1$ and P_L has to be combined to create enough space using the bin P_H, but since P_H is right next to P_L, there is no space for $P_L - 1$.

In the proposed method, we propose a restriction for selecting P_L which takes account the value of P_H:

$$P_L \notin \{P_H - 1, P_H, P_H + 1\} \tag{7}$$

B. Improved Stop Condition

In ACERDH, P_H and P_L are calculated one step ahead to determine if the stop condition will be reached in the next repetition. However, this calculation does not take into the account that the first 16 pixels are not used for histogram shifting for the very last repetition. Thus, to correctly check the stop condition, first 16 pixels should be always excluded from calculating P_H and P_L.

IV. Proposed Method: ACERDH with Distortion Minimization

There are largely two types of distortion which exist in ACERDH. The first type of distortion, referred as splitting distortion, is created when the most frequent peak P_H is split from data hiding. The second type of distortion, referred as combining distortion, is created when histogram bins P_L and $P_L - d$ are combined. In the proposed method, we describe minimization technique for each.

The splitting distortion introduces new details (noise) in the image, while the combining distortion remove details from the image.

A. Splitting distortion minimization

Splitting distortion occurs when the payload is embedded in pixels valued P_H and $P_H - d$. To be exact, only the pixels that are moved from P_H to $P_H - d$ cause the distortion. To minimize this, side information such as the location map, where the size is dependent on the P_L, should be minimized.

(a) Original (b) ACERDH

(c) +SDM (d) +CDM

Fig. 3: Visual results of enhancing the image "Bike". The details of the bike and wheel which were not visible in the original can be clearly seen in ACERDH, +SDM, +CDM.

Rather than choosing P_L as the least frequent pixel, we propose finding P_L, such that number of pixels equal to P_L and $P_L - d$ is minimized. If there are multiple candidates for P_L, we choose the peak P_L such that number of pixels in the peak $P_L - d$ is the smallest. When picked this way, location map will have less number of ones, which translates to less number of pixels valued P_H to be modified to $P_H - d$. Following is the algorithm for splitting distortion minimization:

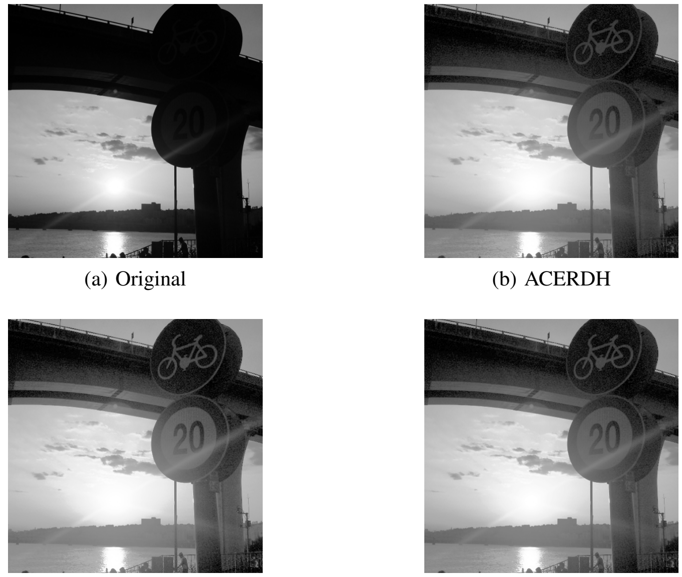
1) Select P_H as the most frequent pixel.
2) Find P_L such that the number of pixels valued P_L and $P_L - d$ are the smallest.
3) If multiple candidates of P_L exist, choose the P_L that has less number of pixels in $P_L - d$.
4) If multiple candidates of P_L still exist, choose the P_L candidate which is the closest from P_S, as there is no clear better choice.

B. Combining distortion minimization

Combining distortion occurs when the pixels valued $P_L - d$ is combined with the pixels valued P_L. To be exact, only the pixels that are moved from $P_L - d$ to P_L cause the distortion.

Rather than choosing P_L as the least frequent pixel, we propose choosing P_L such that the number of pixels valued $P_L - d$ is the minimum. When P_L is selected this way, the distortion from moving pixels valued $P_L - d$ to P_L is minimized. If there are multiple candidates of P_L, we choose the peak P_L that has the smallest number of pixels valued P_L. When chosen this way, it also helps to reduce the splitting distortion by reducing the location map size. Additionally, P_L should be also chosen such that the embedding capacity is big enough for the side information, *i.e.,* selection of P_L is dependent on the selection of P_H. Following is the algorithm for combining distortion minimization:

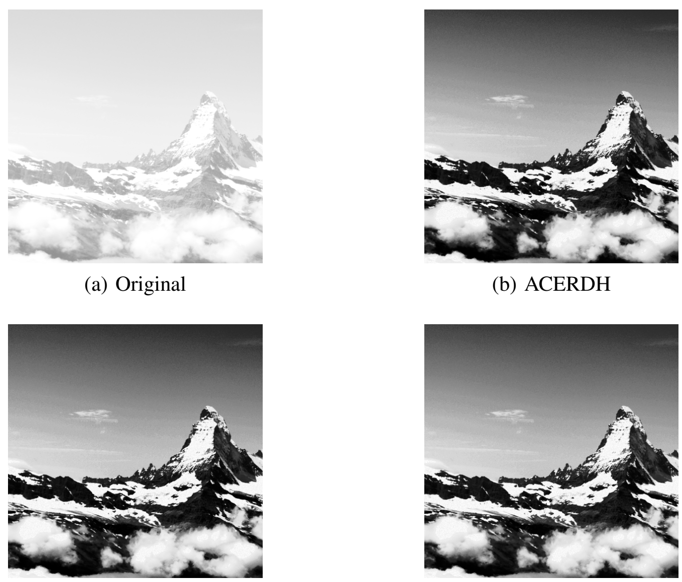
1) Select P_H as the most frequent pixel.
2) Find suitable candidates of P_L, where the side informa-



(a) Original (b) ACERDH

(c) +SDM (d) +CDM

Fig. 4: Visual results of enhancing the image "Sign". The speed limit and the bike path sign which were not visible in the original can be clearly seen in ACERDH, +SDM, and +CDM.



(a) Original (b) ACERDH

(c) +SDM (d) +CDM

Fig. 5: Visual results of enhancing the image "Matterhorn". The under exposed details of the cloud and the mountain from the original image, are clearly visible in ACERDH, +SDM, and +CDM.

(a) Original

(b) ACERDH

(c) +SDM

(d) +CDM

Fig. 6: Visual results of enhancing the image "Hanok". The details of the roofing and the wall, which are not visible in the original image are clearly visible in ACERDH, +SDM, and +CDM.

tion is smaller than the number of pixels valued P_H.

3) Find the candidate for P_L which has the smallest number of pixels valued $P_L - d$.
4) If multiple candidates of P_L exist, choose the P_L that has the smallest number of pixels valued P_L.
5) If multiple candidates of P_L still exist, choose the P_L candidate which is the closest from P_S, as there is no clear better choice.

V. Experimental Results

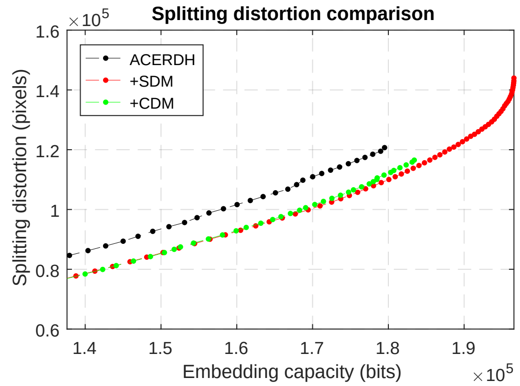
Images from "under and over exposed image suite"[1] are used for the visual comparison and distortion comparison.

A. Visual comparison

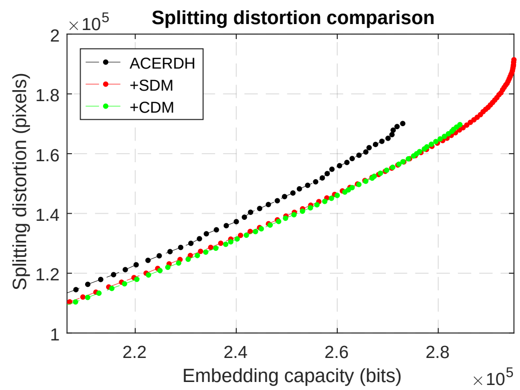
Fig. 3-6 show the visual results of the enhancement. (c) are enhanced images using splitting distortion minimized ACERDH, referred as +SDM, and (d) are enhanced images using combining distortion minimized ACERDH, referred as +CDM.

Although, it is very hard to find the difference between each result, we can notice that images enhanced using +SDM tend to produce the higher contrast images; dark parts of the images become more brighter and the light parts of the images become more darker than other two methods. This is because, splitting distortion minimization process minimizes the location map more. Thus, +SDM achieve greater number of histogram shifting repetition, which increases the contrast more.

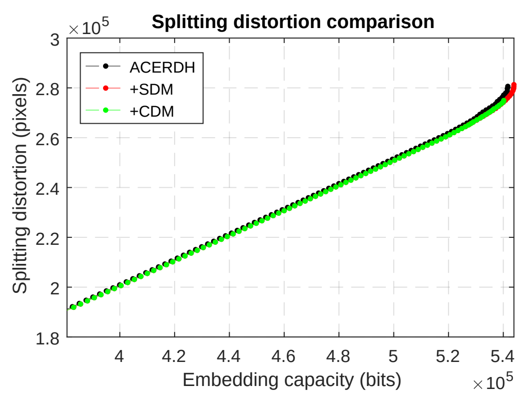
[1]https://github.com/suahnkim/Under-and-over-exposed-images



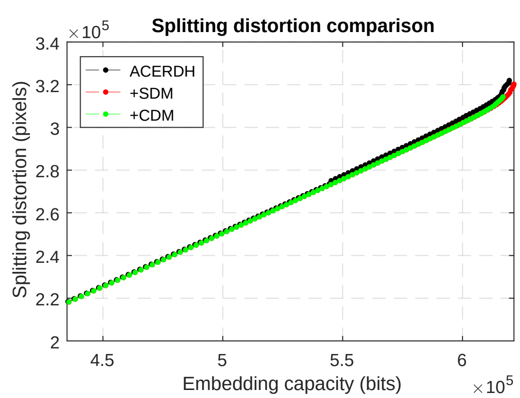
(a) Bike



(b) Sign

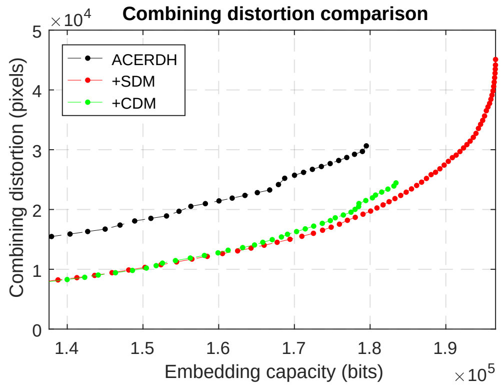


(c) Matterhorn

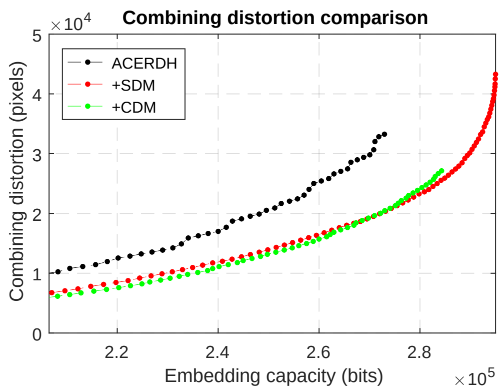


(d) Hanok

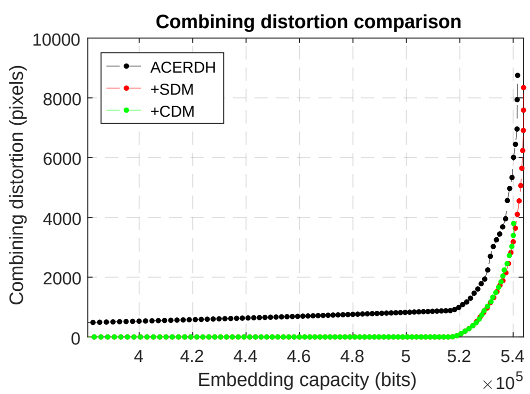
Fig. 7: Comparison of splitting distortion.



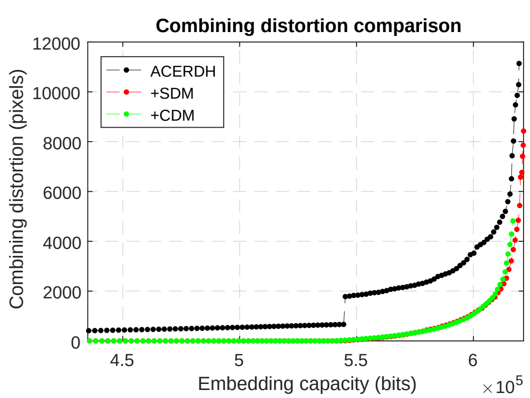
(a) Bike



(b) Sign



(c) Matterhorn



(d) Hanok

Fig. 8: Comparison of combining distortion.

B. Distortion comparison

For distortion comparison, we recorded splitting and combining distortion that occurs during each repetition of the histogram shifting for ACERDH, +SDM, and +CDM against embedding capacity.

Fig. 7 and 8 compares the distortion with respect to the embedding capacity. To make the comparison fair, the distortion is plotted against embedding capacity for each repetition of the histogram shifting.

For the splitting distortion comparison, +SDM provides the lowest splitting distortion in general. For images "Bike" and "Sign", +SDM also provide higher embedding capacity than the other two methods. Although +CDM produces more splitting distortion than +SDM, the difference is small. On the other hand, +CDM produces much less distortion than ACERDH for images "Bike" and "Sign". Furthermore, it has higher embedding capacity than ACERDH as well.

For the combining distortion comparison, +SDM provides the lowest combining distortion for most cases. This may seem like a surprising result because +CDM is specifically design to minimize the combining distortion. But, given that the comparison is done against embedding capacity, it is less surprising; +CDM may sacrifice the embedding capacity at the expense of reducing the combining distortion. Consider a case where peak P_L is much higher than the peak $P_L - d$: the combining distortion is equal to the number of pixels equal to $P_L - d$, but the resulting location map will be big because the peak P_L is high, meaning that less number of bits can be embedded due to the large size of the location map. Despite this, +CDM still is an improvement from ACERDH; +CDM consistently has lower combining distortion and higher embedding capacity than ACERDH.

To conclude, although there were not noticeable differences between +SDM, +CDM, and ACERDH in visual comparison, distortion comparison show that +SDM and +CDM tend to produce less distortion than ACERDH and can achieve higher embedding capacity.

VI. Conclusion

Automatic contrast enhancement using reversible data hiding is a useful solution for automatic image enhancement. In this paper, we improve the existing work by Kim et al. [1], by proposing two minor improvements and two novel distortion minimization methods for ACERDH. The experiment shows that the proposed method result in higher embedding capacity and lower distortion from histogram shifting.

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