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# Evaluation of Reversible Image Data Hiding with Contrast Enhancement

**Athira K**
M Tech Student, Dept of. ECE, LBS College of Engineering, Kasaragod, India

**Abstract:** Reversible data hiding (RDH) embeds a piece of information into a host signal to generate a marked one, so that the original signal is exactly recovered after the extraction of embedded data. For the images obtained with poor illumination, visual quality is more important than high PSNR value. The DH algorithm keeps the PSNR value high and enhances the contrast of the host image to improve the visual quality. The highest two bins in the histogram of the input image are shifted for data embedding, such that histogram equalization can also performed simultaneously by repeating the embedding process. The original image is completely recoverable by embedding side information along with the message bits to form a host image. Evaluation of images is an important step after data hiding, for determining how much the contrast has been enhanced. Quality of image is usually assessed using image quality metrics relative contrast error (RCE), relative entropy error (REE), relative mean brightness error (RMBE), relative structural similarity (RSS), peak signal to noise ratio (PSNR) and global contrast factor (GCF). This paper is a study of the various quantitative metrics for evaluating contrast enhancement. The results show that the visual quality can be preserved by embedding a considerable amount of message bits into the input images.

**Keywords**: Reversible data hiding, Contrast Enhancement, Histogram binning, Steganography.

## I. INTRODUCTION

Data hiding is the process of embedding some valuable information onto images. In most applications, the data that is hidden is related to authentication in which invisibility is a major requirement. Data hiding [1] is mostly useful in the field of sensitive applications such as in sending authentication data. . In most cases, the image will experiences some distortions by hiding data and cannot be converted back to the original image. That is, some permanent distortion occurs in the image even after the removal of the hidden data. This is a lossy hiding technique.

Reversible data hiding (RDH) [2] is also referred to as invertible or lossless data hiding which has been studied in depth in the field of signal processing. In RDH algorithm, watermarked image is generated by hiding a piece of information into the image, from which the original image can be recovered after the extraction of hidden data. Lossless data hiding is studied as a powerful and popular technique to protect copyright in many sensitive applications such as law enforcement, medical diagnosis, and remote sensing. Visible watermarking and invisible watermarking are the two types of watermarking algorithms. The watermark should be perceptually visible and robust for visible watermarking [3]. For invisible watermarking [4, 5, 6, 7] the watermark should be perceptually transparent and robust.

The lossless visible watermark technology would damage the image quality, limits its applications. The non-destructive image reproduction, overcomes the limitations

of destruction in the image quality. In covert communications, the hidden data may often be irrelevant to the cover media. In authentication, however, the embedded data are closely related to the cover media. In these two types of applications, invisibility of hidden data is an important requirement.

Reversible data algorithm uses histogram binning technique. This paper aims at evaluating the RDH algorithm with various quantity measures used for evaluating the contrast enhancement

This paper is organised as follows. Section I gives an introduction of reversible watermarking technique. Section II describes the detailed algorithm of reversible hiding. Section III provides the description of various quality metrics for contrast enhancement. The experimental results are summarised in section IV. Finally the conclusion is drawn in section V.

## II. REVERSIBLE DATA HIDING ALGORITHM

The reversible algorithm is performed by histogram binning. Highest two bins in the histogram were chosen for data embedding. The peak values are shifted according to the bits in the message data. Bin values in between these peaks are not changed. But the outer values are shifted outward for contrast enhancement [8]. This way achieves both contrast enhancement and data embedding. The side information was also embedded along with the message bits for exact recovery of original image from stego image.

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A. Data Embedding

Histogram of image is computed first. $I_S$ and $I_R$ be the highest two peaks in the histogram. In which $I_S$ is the smaller peak value. Pixels in the ranges 0 to L and 256-L to 256 are pre-processed to avoid overflows and underflows, where L is the number of iterations. Then location map is generated by assigning one value to the modified pixel and zero value to the unchanged one. The location map is then compressed using run-length encoding algorithm [9]. Compressed location map is also included in the message bits to be hidden. Secret information is embedded on the peak values by shifting according to the below equation.

$$i' = \begin{cases} i-1, & for\ i < I_S \\ I_S - bk, & \text{for } i = I_S \\ i, & \text{for } Is < i < I_R \\ I_R + bk & \text{for } i = I_R \\ i+1 & \text{for } i > I_R \end{cases}$$

The final peak values are required for the recovery process. For that, LSBs of first sixteen pixels in the image is replaced with this 8 bit $I_S$ and $I_R$ values by bitwise operation. Then the original LSBs are embedded along with message bits. The previous peak values, length of compressed location map, original LSBs, and the value of L are embedded in the final iteration. The marked image is finally generated.

B. Data Extraction

LSB's of first 16 pixels in the bottom raw of the image is extracted first. Hence the final peak values are obtained. The embedded bits in the final iteration are extracted using the below equation.

$$bk' = \begin{cases} 1, & if\ i' = I_S - 1 \\ 0, & \text{if } i' = I_S \\ 0, & \text{if } i' = I_R \\ 1, & \text{if } i' = I_R + 1 \end{cases}$$

Then the histogram is reconstructed using below equation.

$$i = \begin{cases} i' + 1, & i' < I_S - 1 \\ Is, & i' = I_S - 1 \text{ or } i' = I_S \\ I_R & i = I_R \text{ or } i' = I_R + 1 \\ i - 1, & i' > I_R + 1 \end{cases}$$

The process of extraction and reconstruction is repeated until all the embedded information is recovered. Compressed location map is expanded using run-length decoding algorithm. The original LSB are restored. The image is successfully recovered back.

## III. QUALITY METRICS FOR EVALUATING IMAGE CONTRAST

Qualitative evaluation of image is an important step after processing, to measure how well the image is being processed. Quality of image is usually obtained using image quality metrics. Image enhancement basically deals with improving the image quality for better vision. Contrast enhancement is one of the important issues in image processing. Poor illumination, wrong lens aperture settings, lack of dynamic range in image sensor etc, results in poor contrast. Improving the dynamic range of pixels in the image improves the visual quality is the idea behind contrast enhancement. Histogram equalization [10] is a generally used technique for improving contrast of an image. Some minor details are lost after histogram equalization.

Most of the commonly used metrics cannot adequately describe the visual quality of the enhanced image. Six indicators are used for measuring image quality. The six indicators used are relative entropy error (REE), relative contrast error (RCE), relative mean brightness error (RMBE), relative structural error (RSS), peak signal to noise ratio (PSNR) and global contrast factor (GCF). A global contrast factor metric is proposed that is useful for measuring the improvement

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in contrast . It is computationally simple and can be used for all types of images. The four indicators [11] REE, RCE, RMBE and RSS have values between zero and one.

REE uses quantified entropy values to measure the degree of enhancement between original image and modified image. $E_{New}$ is the entropy of the modified image and $E_{Original}$ is the entropy of the original image. A value of .5 is added to reach the required range. For improved quality REE should be greater than .5. Otherwise image is deteriorated.

$$REE = \frac{ENew - EOriginal}{2 \times \log_2 L} + 0.5$$

RCE uses standard deviation to measure the degree of contrast enhancement between the original image and modified image. $Std_{new}$ is the standard deviation of the modified image and $Std_{Original}$ is the standard deviation of the original image. RCE should be greater than .5.

$$RCE = \frac{STDnew - STDoriginal}{2 \times \log_2 L} + 0.5$$

RMBE uses mean brightness to measure the degree of contrast enhancement between the original image and modified image. $M_{new}$ is the standard deviation of the modified image and $M_{Original}$ is the standard deviation of the original image. RMBE should be greater than .5.

$$RMBE = 1 - \frac{|Moriginal - Mnew|}{L - 1}$$

RSS indicates the structural similarity between the images. It is measured by calculating the root mean square error between the original and contrast enhanced images. Its value should be greater than .5.

$$RSS = 1 - \frac{RMSE}{L - 1}$$

PSNR is calculated based on the mean square error between original and watermarked image. For a high quality image PSNR value will be higher. MAX is the maximum intensity of the image.

$$PSNR = 10 * \log_{10}(\frac{MAX^2}{MSE})$$

Instead of focusing only on the ratio of the darkest and the lightest spot, GCF [12] uses local contrasts at various resolution levels. Visual system is not equally sensitive to changes at various frequencies. So we cannot simply compute the global contrast as the average of local contrasts. The solution is to build a weighted average of local contrasts. Let i is the pixel intensity of the image having values in the range of {0, 1, 2, ……255}. Initially gamma correlation is applied with value of γ equal to 2.2. Then the input values are scaled to [0,1]. The scaled and correlated value is denoted as linear luminance l. $R_{i+1}$

$$l = (\frac{i}{255})\gamma$$

The perceptual luminance R is

$$R = 100 \times \sqrt{l} = 100 \times \sqrt{(\frac{i}{255})\gamma}$$

The local contrast is computed as the average of differences obtained by calculating R between each pixel and its four neighbours. Assuming the image is having w pixels wide and h pixels high.

$$lc_i = \frac{|R_i - R_{i-1}| + |R_i - R_{i+1}| + |R_i - R_{i-w}| + |R_i - R_{i+w}|}{4}$$

 

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The average local contrast for the current pixel is computed as

$$C_i = \frac{1}{w \times h} \sum_{i=1}^{w \times h} lc_i$$

$C_i$ for various resolutions need to be calculated. Once the $C_i$ of original image is obtained, a smaller resolution image is build and four original pixels are converted into one super pixel. Then image width is half of the original width and height is half of the original. The super pixel value is computed as average linear luminance is then converted to perceptual luminance. $C_i$ for this resolution can be computed and the process is continued until only few huge super pixels are remain in the image. With average local contrast $C_i$ and weigh factor $w_i$ , the global contrast factor is obtained as

$$GCF = \sum_{i=1}^{N} w_i \times C_i$$

where N is the number of iterations.

## IV. EXPERIMENTAL RESULTS

The gray scale images 'Lena', 'Barbara', and 'Boat' were chosen for experiments. These were resized to 256×256. The input images are shown in Figure 1 (a), (b) and (c).

a)

b)

c)

Fig1. a) Lena b) Barbara c) Boat

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These images are hidden with the secret information .The results for 10 iterations were shown in figure 2. The contrast of the resultant mages were quantitatively evaluated using the quality metrics, RCE, REE, RMBE, RSS and PSNR are shown in Table I and the corresponding graphs are shown in figure 3 and 5. GCF is calculated for resolutions of 4, 6, 8 and 9 are shown in Table I and the corresponding graphical evaluation is shown figure 4.

a)
b)
c)


Fig. 2. Marked images of a) Lena b) Barbara c) Boat

TABLE I
QUALITY MEASURES FOR STANDARD IMAGES

| Image | REE | RCE | RSS | RMBE | PSNR |
|---|---|---|---|---|---|
| Lena | 0.5109 | 0.5077 | 0.9728 | 0.9904 | 31.2995 |
| Barbara | 0.5096 | 0.5022 | 0.9834 | 0.9966 | 35.5825 |
| Boat | 0.5198 | 0.5001 | 0.9725 | 0.9921 | 31.2156 |

TABLE II
GCF FOR 4, 6, 8 AND 9 RESOLUTIONS FOR STANDARD IMAGES

| Image | GCF | | | |
|---|---|---|---|---|
| | 4 Res. | 6 Res. | 8 Res. | 9 Res. |
| Lena | 3 | 5 | 6 | 7 |
| Barbara | 3 | 5 | 9 | 10 |
| Boat | 3 | 5 | 7 | 8 |

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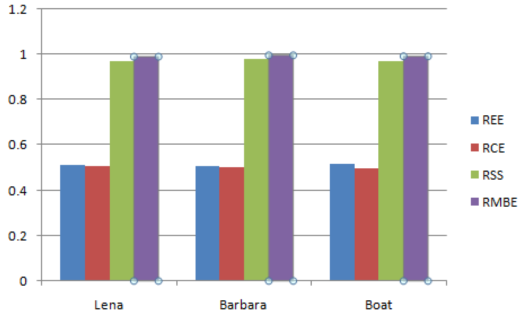


Fig. 3. Quality measures REE, RCE, RSS and RMBE values for input standard images Lena, Barbara and Boat

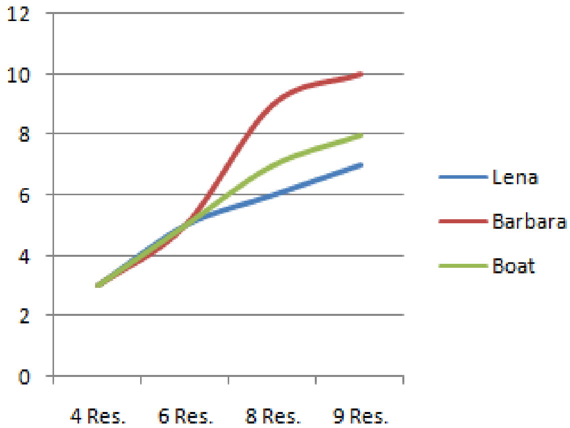


Fig. 4. GCF values for 4, 6, 8 and 9 resolutions for input standard images Lena, Barbara and Boat

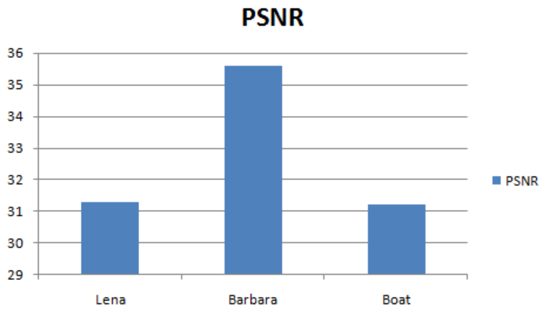


Fig. 5. PSNR values for input standard images Lena, Barbara and Boat

The same experiments are repeated for low contrast images Forest, Hip and Lung and are resized to 256×256 were shown in figure 6. The marked images are also shown in figure 7. The quality measures RCE, REE, RSS, RMBE and PSNR is calculated as shown in Table III. Also the corresponding graphs are plotted and are shown in figure 8 and 10. GCF for various resolutions are calculated as shown in Table IV. A graphical evaluation is also shown in fig 9.

a)

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b) 

c) 

Fig. 6. a) Forest b) Hip c) Lung

a) 

b) 

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c) 

Fig. 7. Hiding bits in a) Forest, b) Hip and c) Lung images

TABLE III
QUALITY MEASURES FOR LOW CONTRAST INPUT IMAGES

| Image | REE | RCE | RSS | RMBE | PSNR |
|---|---|---|---|---|---|
| Forest | 0.5258 | 0.5025 | 0.9832 | 0.9919 | 35.5016 |
| Hip | 0.5129 | 0.4977 | 0.9894 | 0.9720 | 39.4980 |
| Lung | 0.5096 | 0.5030 | 0.9819 | 0.9929 | 34.8387 |

TABLE III
GCF FOR 4, 6, 8 AND 9 RESOLUTIONS FOR LOW CONTRAST INPUT IMAGES

| Image | GCF | | | |
|---|---|---|---|---|
| | 4 Res. | 6 Res. | 8 Res. | 9 Res. |
| Forest | 1 | 1 | 3 | 3 |
| Hip | 1 | 3 | 5 | 6 |
| Lung | 1 | 3 | 5 | 6 |

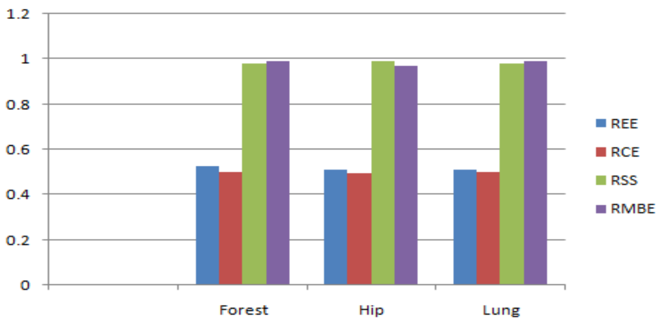
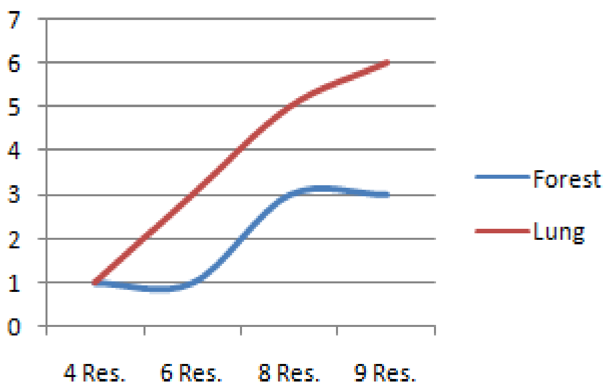



Fig. 8. Quality measures REE, RCE, RSS and RMBE values for low contrast input images Forest, Hip and Lung




a)

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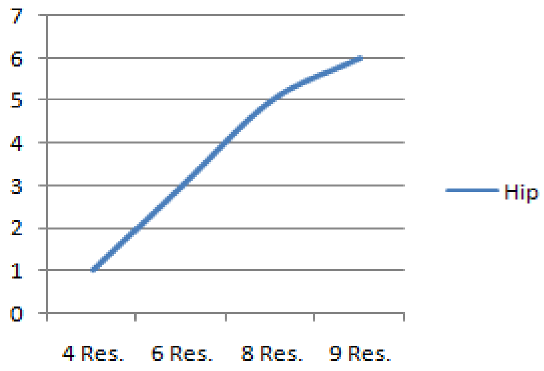


b)

Fig . 9. GCF values for 4, 6, 8 and 9 resolutions for input low contrast images a) Forest, Lung and b)Hip

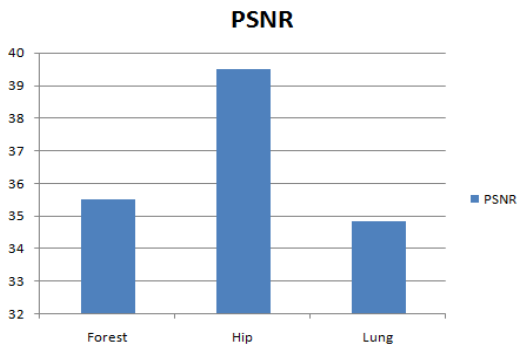


Fig. 10. PSNR values for low contrast images Forest, Hip and Lung

Results show that better contrast characteristics are obtained for both low contrast and standard images. REE values greater than 0.5 shows that image data is better preserved. Also the RCE values for both images shows enhancement in contrast. For both type of images RSS values are always greater than 0.9.so there is higher structural similarity between original and marked image. Also the brightness error between original and marked image is very low for values closer to 1. Results show effective maintaining of mean brightness between original and marked image. Higher PSNR values are obtained for both types of images.

GCF values for standard and low contrast images increases with increase in the number of resolutions. For 4 resolutions the standard images have GCF values equal to 3.but low contrast images have value one. Higher GCF values are obtained for standard images. Indicates that the standard images have higher contrast factor. Also for lower number of resolutions each type of images has similar GCF values. GCF values shows improvement in contrast for marked images.

## IV. CONCLUSION

An evaluation of reversible data hiding algorithm is performed with contrast enhancement. The highest two bins in the histogram are iteratively shifted for data embedding. Hence it achieves both contrast enhancement and reversible data hiding simultaneously. Experiments were conducted on standard images and low contrast images and the results evaluated using quality metrics, Relative contrast error (RCE), Relative mean brightness error (RMBE), Relative structural similarity (RSS), Relative entropy error (REE), Peak signal to noise ratio (PSNR) and Global contrast factor (GCF). Global contrast factor measures the contrast at various resolutions and gives the overall contrast. Results show a clear improvement in contrast characteristics for marked images. The original image is completely recovered after the secret data is extracted.

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