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Comparative Analysis of Various Contrast Enhancement Techniques for Underwater Images

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ABSTRACT: Underwater images often suffer from poor contrast and visibility conditions when compared to images from clearer environment resulting in substandard quality for image analysis. Image Contrast Enhancement techniques are important for any subjective evaluation of image quality. Contrast enhancements improve the quality of details in the images by enhancing the brightness difference between objects and their background. Histogram equalization is one of the widely known techniques for enhancing the contrast of the images. In the proposed work, a comparative analysis of various local contrast enhancement techniques for underwater images such as Adaptive Histogram Equalization, Fully Automated Contrast Limited Adaptive Histogram Equalization (Auto-CLAHE) and various global contrast enhancement techniques such as Non-Parametric Modified Histogram Equalization (NMHE), Brightness Preserving Bi-Histogram Equalization (BBHE) and Recursive Separated Exposure based Sub-Image Histogram Equalization (RS-ESIHE) are presented. Various parameters such as Peak Signal to Noise (PSNR), Entropy, Global Contrast (GC), Structural Similarity Index (SSIM) and Absolute Mean Brightness Error (AMBE) are calculated for the resultant images to estimate the performance of the above mentioned techniques.

KEYWORDS: Contrast Enhancement; Histogram Equalization; Underwater Image Processing; BBHE; CLAHE; NMHE; RS-ESIHE

I. INTRODUCTION

Oceans play an important role in delivering animal protein, are a cornerstone of the transition to renewable energy, and are a future source for mineral resources. Due to the rapid improvements in image processing technology along with its associated challenges [1], the researchers within the field of marine department and image processing undertook several studies to face problems regarding the quality of the underwater images. Contrast enhancement of underwater images to make them more effective is one of the principle goals of this investigation [2]. Contrast is created in an image by the difference in luminance reflected from two adjacent surfaces. Thus object contrast is an important factor in the perception of the visual quality of an image and in its usefulness for object recognition and image analysis applications. The goal of contrast enhancement is to provide a more appealing image, with easier differentiation of objects, and improved clarity of object features and surface details.

This paper presents a review of various techniques that can be used for contrast enhancement [3]. These techniques are categorized as global enhancement techniques and local enhancement techniques. Section II discusses the local contrast enhancement techniques based on Histogram Equalization such as Adaptive Histogram Equalization (AHE) and Fully automated CLAHE (Auto-CLAHE). Section III deals with global enhancement Histogram equalization techniques such as Non-Parametric Modified Histogram Equalization (NMHE), Brightness Preserving Bi-Histogram Equalization (BBHE) and Recursive Separated Exposure based Sub-Image Histogram Equalization (RS-ESIHE). In Section IV, each of these techniques is implemented and the performance of each method is analyzed using image quality and error parameters. Section V concludes the paper.

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II. Local Contrast Enhancement

Local contrast enhancement attempts to enhance the details in the image by letting a small window slide through every pixel of the input image sequentially. Only those blocks of pixels that fall in this window are enhanced. And then gray level mapping is done only for the center pixel of that window. Thus, it makes good use of local information.

A. *Adaptive Histogram Equalization (AHE):*

Histogram equalization (HE) is a widely used technique for contrast enhancement because it is simple to use and better in performance on all types of images [4]. It is most commonly used in the areas like medical image processing, radar signal processing etc. HE works by flattening the histogram of input image and stretches dynamic range of gray levels by using cumulative density function (CDF) of the image. AHE is an extension to traditional Histogram Equalization technique [5]. Unlike HE, it operates on small data regions (tiles), rather than the entire image. The contrast of each region is enhanced, so that the histogram of the output region approximately matches the specified histogram. The neighbouring regions are then combined using bilinear interpolation in order to eliminate artificially induced boundaries.

In adaptive histogram equalization, the main idea is to take into account histogram distribution over local window and combine it with global histogram distribution. The size of the neighbourhood region is a parameter of the method. It constitutes a characteristic length scale: contrast at smaller scales is enhanced, while contrast at larger scales is reduced. When the image region containing a pixel's neighbourhood is fairly homogeneous, its histogram will be strongly peaked, and the transformation function will map a narrow range of pixel values to the whole range of the result image. This causes AHE to over amplify small amounts of noise in largely homogeneous regions of the image [6].

B. Fully Automated Contrast Limited Adaptive Histogram Equalization (Auto-CLAHE)

The CLAHE method applies histogram equalization to sub-images. Every pixel of original image is represented as focal point in the sub- image. The first histogram of the sub picture is cut and the cut pixels are redistributed to each gray level. The new histogram is not quite the same as the first histogram on the grounds that the intensity of every pixel is inhibited to a client determined maximum. Consequently, CLAHE can lessen the enhancement of noise [7].

It has been found that the choice of clip limit is very crucial for optimal enhancement using CLAHE. The correct choice of the clip level depends very much on the block size and the number of bins in the local histogram. In this algorithm, the estimation of the clip limit (CL) and window size (N) is done automatically from the given input image. To each value of N, from N=2x2 to N=32x32 (images get blurry after 32x32 window size) the window size with the maximum entropy is applied. The maximum bin height is taken in the local histogram of the sub-image by calculating the mean value of the sub image and the clipped pixels are redistributed equally to each gray-level [8].

III. Global Contrast Enhancement

Global histogram equalization is simple and fast, and it cannot adapt to local brightness of input image as it uses only global histogram information over the whole image. Thus, it does not focus on local featured and helps in improving the overall contrast of an image. Some of the global enhancement techniques are explained in this section.

A. *Brightness Preserving Bi-Histogram Equalization (BBHE):*

In this technique, the input image is decomposed and two sub images are formed on the bases of mean value. One sub image contains the set of samples that are less than or equal to mean whereas the other sub image is the set of samples greater than mean. Then the method equalizes both sub images independently according to their respective histograms with a constraint that samples in the first sub image are mapped in the range from minimum gray level to input mean and samples in second sub image are mapped in the range from mean to maximum gray level. That means one sub image is equalized over the range up to mean and other sub image is equalized over the range from mean based on the respective histograms. The resultant equalized sub images are bounded by each other around input mean, which has an effect of preserving the mean brightness.

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BBHE has an advantage that it preserves mean brightness of the image while enhancing the contrast and, thus, provides much natural enhancement that can be utilized in consumer electronic products[9].

B. *Non-parametric Modified Histogram Equalization (NMHE)*

This technique is independent of parameter setting for a given dynamic range of the input image. The algorithm uses the modified histogram for spatial transformation on grey scale to render a better quality image irrespective of the image type. Added to this, two variants of the methodology are considered, one of which preserves the brightness of original image while the other variant increases the image brightness adaptively, giving it a better look.

This method improves the contrast of an image, which modifies the image by an adaptive transformation rather than solving any optimization problem. The novelty of the technique lies in the use of image statistics to compute a spike free modified histogram, which is then equalized to render an image with better visual attribute. A higher degree of entropy preservation between the input and output images, has shown that NMHE can preserve the overall content of the image, while enhancing the image contrast [10].

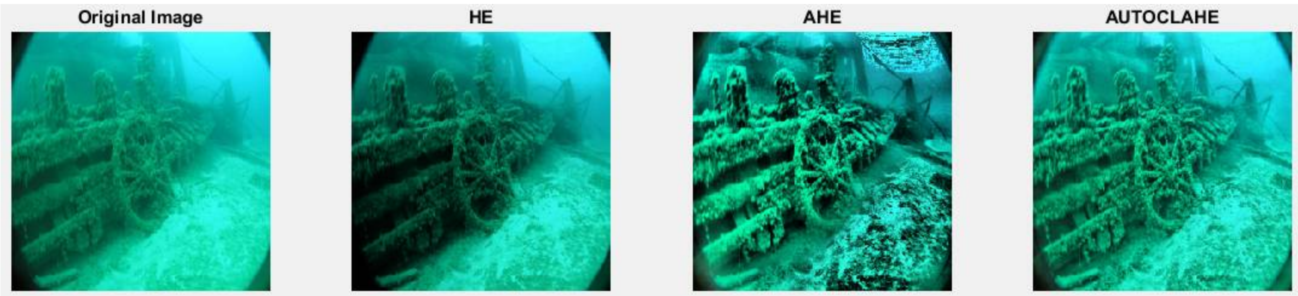
C. *Recursively Separated ESIHE (RS-ESIHE)*

Conceptually, RS-ESIHE is a recursive version of ESIHE, which performs recursive decomposition of the histogram. ESIHE decomposes the input histogram only once based on the exposure threshold while RS-ESIHE decomposes it recursively based on exposure thresholds of individual sub histograms up to a recursion level r, generating 2^r sub- histograms. The decomposed sub-histograms are then equalized individually. In other words, unlike recursive exposure based method, it performs recursive divisions of histogram based on exposure threshold of individual sub histogram up to a defined recursion level which are further equalized individually. For simplicity recursion level, r is taken as two [11].

IV. IMPLEMENTATION & RESULTS

All the above mentioned techniques are implemented in MATLAB 7.14 Version R2015b with Image Processing Toolbox. The images selected for this study are underwater images taken from SUN database [12]. A set of quality metric parameters such as Entropy [13], Global Contrast (GC) [14], Peak Signal to Noise Ratio, Structural Similarity Index and Absolute Mean Brightness Error (AMBE) [15] are used to measure the quality of the enhanced image with respect to the original image.

The local contrast enhancement techniques are evaluated with HE, AHE, Auto CLAHE techniques. It can be seen from Fig. 1 that Auto CLAHE produces better quality images while preserving the edges than AHE while HE produces dark spots, AHE over enhances the noisy regions. These performances are also measured quantitatively by various metrics which is given in the table. It is evident that Auto CLAHE provides better contrast enhancement than the other techniques with highest values of PSNR and lower values of AMBE.



a.shipwreck

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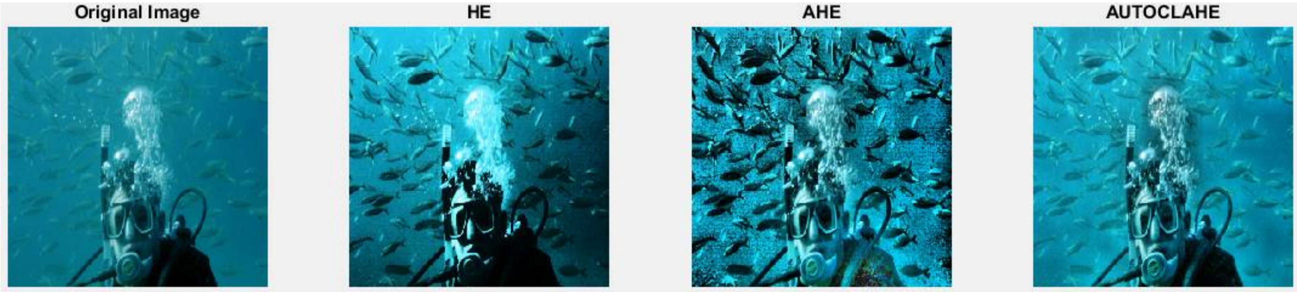
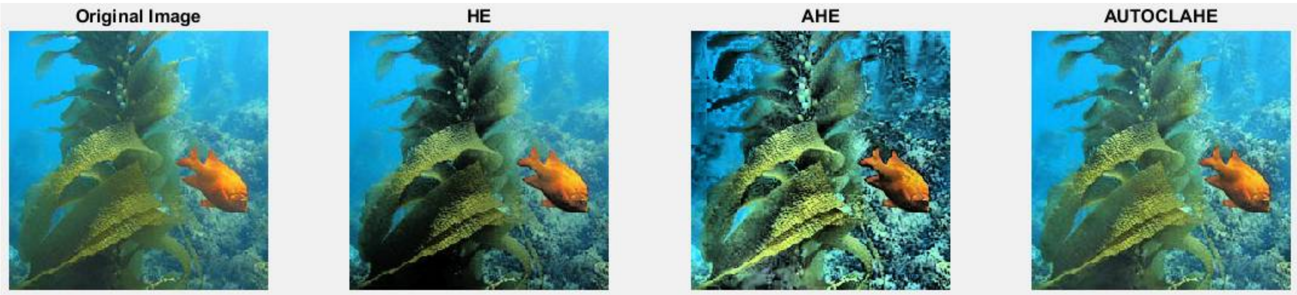


b.sea diver



c.kelp forest

Fig. 1. Sample images and their enhanced results for local enhancement techniques: HE, AHE, CLAHE, Auto CLAHE for various underwater images. (a) shipwreck, (b) sea diver, (c) kelp forest

TABLE I. COMPARISON OF VARIOUS PARAMETERS FOR THE ABOVE SAMPLE IMAGES WITH LOCAL ENHANCEMENT:

		PSNR	GC	SSIM	ENTROPY	AMBE
Shipwreck	HE	5.7084	0.3162	0.000033674	7.0085	310.1346
	AHE	5.7055	0.3288	0.000062701	7.4156	310.1309
	Auto CLAHE	5.7124	0.33	0.000068102	7.5649	309.9102
Sea diver	HE	7.5168	0.4221	0.000057685	7.2115	264.0073
	AHE	7.5156	0.4191	0.0016	7.5643	263.983
	Auto CLAHE	7.5222	0.3680	0.00012213	7.3527	263.7844
Kelp forest	HE	6.418	0.497	0.00004588	7.477	317.2307
	AHE	6.4157	0.5819	0.000083499	7.8041	317.1735
	Auto CLAHE	6.4225	0.4434	0.000077141	7.8107	316.9730

The global contrast enhancement techniques are evaluated with BBHE, NMHE and RS-ESIHE techniques. It can be observed in Fig.2 that RS-ESIHE technique has better PSNR values and is closely followed by NMHE. BBHE performs better in terms of brightness preservation and entropy while also resulting in a slight over enhancement in colour channels.

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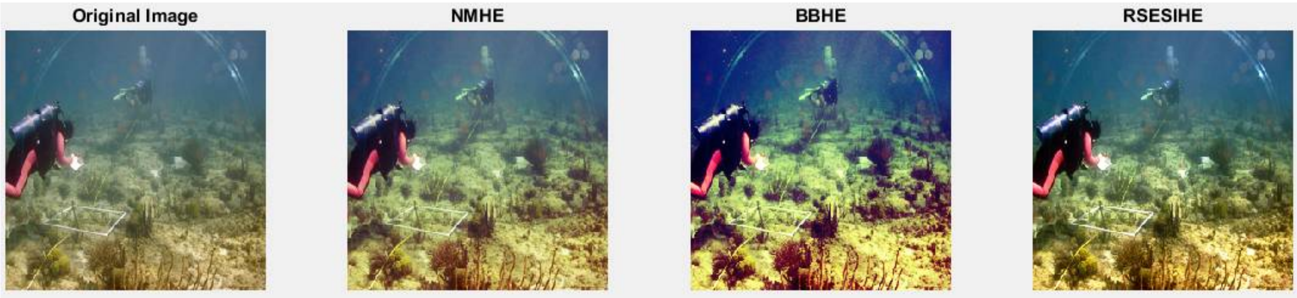

a.exploration

b.Coral reef

c.fish

Fig. 2. Sample images and their enhanced results for global enhancement techniques: NMHE, BBHE and RSESIHE for various underwater images. (a) exploration, (b) coral reef, (c) fish

TABLE II. COMPARISON OF VARIOUS PARAMETERS FOR THE ABOVE SAMPLE IMAGES WITH GLOBAL ENHANCEMENT:

		PSNR	GC	SSIM	ENTROPY	AMBE
exploration	NMHE	26.3433	6.6005	0.9415	7.3951	24.2639
	BBHE	18.3957	9.7205	0.7489	7.6014	64.6874
	RS ESIHE	33.7952	5.514	0.9715	7.2629	7.7678
Coral reef	NMHE	18.7982	7.7515	0.74	6.6423	53.2711
	BBHE	12.9065	14.8317	0.5438	6.9145	79.5344
	RS ESIHE	26.4658	4.2432	0.9212	6.6848	18.3844
fish	NMHE	24.1431	6.9821	0.8884	6.8213	25.8672
	BBHE	14.3705	12.556	0.572	7.2265	68.7439
	RS ESIHE	29.9762	4.7808	0.8803	6.9111	12.7453

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V. CONCLUSION

In this paper, a review of various contrast enhancement histogram equalization techniques has been presented. These techniques which are broadly categorized into local and global methods has been implemented and compared. The performance of these methods was analysed for underwater images. From the experimental results, it is found that Auto CLAHE performs well in local enhancement techniques and RS-ESIHE performs well in global enhancement techniques. In future, images taken from a wide range application such as aerial, infrared and medical images can be studied so that it can be deduced which method suits well for each application. Also, metrics specifically measuring colour parameters can be considered for colour images.

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