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Underwater Image Enhancement Algorithm Based on Logarithmic Transform Histogram Matching With Spatial Equalization

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Abstract— **In this paper a novel algorithm is proposed for underwater image enhancement. The proposed method based on combined local and global image processing in the frequency domain. The basic idea is to apply logarithmic transform histogram matching with spatial equalization approach on different image blocks. The resulting image is a weighted mean of all processing blocks driven through optimization of measure of enhancement (EME). Some presented experimental results illustrate the performance of the proposed algorithm on real underwater images in comparison with the classical contrast enhancement techniques and adaptive histogram equalization techniques.**

Keywords— underwater image; enhancement; equalization; logarithmic transform; the measure of enhancement (EME).

I. Introduction

Image enhancement is the important tool in the image processing with a purpose to improve the visual appearance of the image or to provide "better" transform for future analysis (segmentation, contour detection and recognition) [1, 2]. In many cases, enhancement procedures are used as a preprocessing step for image visualisation.

Underwater cameras are widely used to observe the sea floor. They are usually included in autonomous underwater vehicles (AUVs) [3].

Underwater image processing is challenging problem and its importance for the environment [4]. The quality of underwater images is still much worse than that of air images because of the limitations imposed by the physical properties of the water medium [4]. Underwater images usually appear foggy and hazy. Such images are characterized by their poor visibility because light exponentially attenuated underwater. This leads to image has low contrast. Therefore, underwater images can hardly be used for understanding without image enhancement processing.

Enhancement approach can be classified into two categories: spatial and frequency domain methods [5].

The first group use spatial domain image processing which directly manipulates the pixels. Many spatial image enhancement methods are based on histogram analysis and modification; other methods are based on the local contrast transformation [1].

The most popular image enhancement method is histogram equalization. It is a global processing approach, so the entire tone of the image has been changed like more bright or dark image. In many cases, these methods extend the dynamic range of an image in local regions, leading to artefacts and overall tonal change of the image.

The second group use transformation in the frequency domain through modification magnitudes and altering the frequency content of the image. These enhancement techniques use frequency transform such as DCT, Fourier, etc. Sometimes the image properties such as low and high-frequency coefficient's histograms may be so tightly packed that distinguishing them from one another may be impossible [1, 6]. Logarithmic transform allows improving the difference between levels of images [1].

Adaptive histogram equalization (AHE) is an image processing technique used to improve contrast in images [7, 8]. An adaptive version of this algorithm called contrast limited adaptive histogram equalization (CLAHE) [8,9].

Each of these methods has strong and weak points. Hence, the combination of the above methods is used to enhance the image through transform histogram mapping technique [10].

In this paper, novel enhancement technique for underwater images is investigated. The proposed contribution is based on logarithmic transform coefficient histogram mapping technique with adaptive histogram equalization on different image blocks.

II. Proposed Algorithm

The block diagram of the proposed enhancement algorithm for the underwater image is depicted in Fig. 1:

The procedure for the proposed algorithm is expressed as following steps:

Input - Original Image.

Step 1 – Image splitting.

We split image in moving windows on disjoint blocks with different sizes (8 by 8, 16 by 16, 32 by 32 and, i.e.) (Fig. 2).

For every sub-image, we use the frequency domain enhancement method based on the logarithmic transform histogram matching with spatial equalization. The block diagram of the enhancement processing shows in Figure 3.

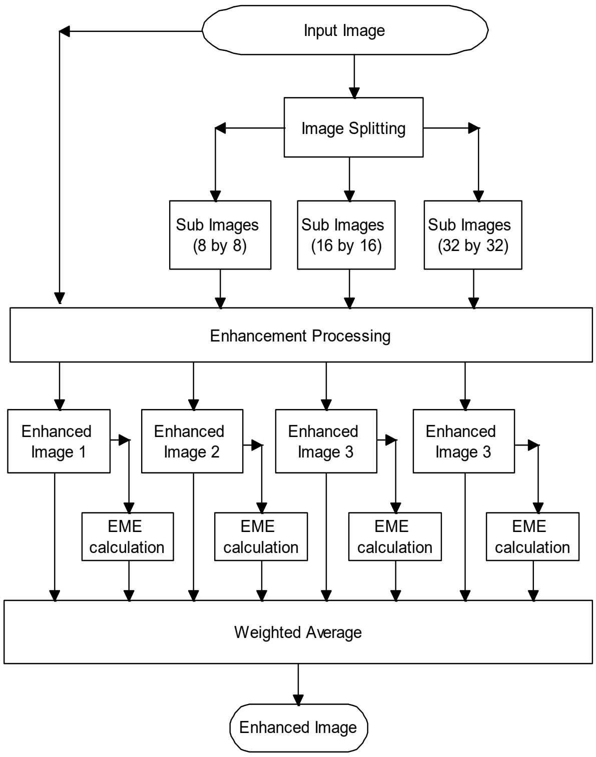

Fig. 1. Block diagrams of the proposed algorithm.

We perform image transformation, which needs to be enhanced, then manipulated the transform coefficient, and then perform the inverse orthogonal transform.

In proposed approach is used Discrete Fourier Transform as orthogonal transform functions. The histogram of this data is usually compact and uninformative. Logarithmic transform in our scheme helps to maps a narrow range of low grey level values into a wider range of the output level. This type of transformation is used to expand the values of dark pixels in an image while compressing the higher-level values [11].

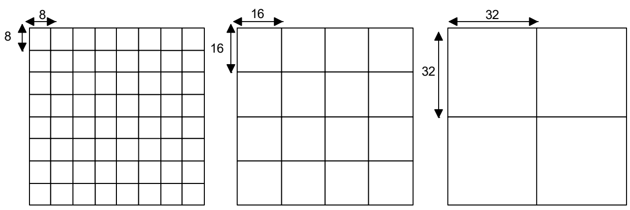

Fig. 2. Image splitting.

Step 2 – Enhancement Processing.

The Log transformation includes two steps:

- the creation of a matrix to preserve the phase of the transformed image, which is given by the equation:

$$\Theta(i,j) = angle(\dot{X}(i,j)).$$

The angle function returns the angle of the coefficient. And will be used to restore the phase of the transform coefficients.

- the transformation of the coefficients according to the following equation:

$$\hat{X}(i,j) = \gamma \ln(\eta |\dot{X}(i,j)| + \lambda),$$

where η, γ, and λ are enhancement parameters, usually set to 1.

To return the coefficients to the standard transform domain the signal is exponentiated, and the phase is restored as shown by the following equation:

$$\widetilde{X}(i,j) = e^{\hat{X}(i,j)} \cdot e^{j\Theta(i,j)}.$$

This allows to keep the overall image characteristics and return them to the original image.

It is important to keep the phase information unchanged because the angle contains most of the images underlying characteristic information [12].

Histogram equalization maps the input image's intensity values so that the histogram of the resulting image will have an approximately uniform distribution as follow [12]:

$$s = T(r) = \int_0^r p_r(w)dw,$$

where r is the grey level of an input image, T is the transformation function, s is the transformed value, p_r is the probability density function of the given image and p_z is the specified probability density function.

The following equation can obtain the probability density function of r and respectively:

$$p_s(s) = p_r(r)\left|\frac{dr}{ds}\right|.$$

The adaptive histogram equalization is operating on small local regions, rather than the global image. The contrast transform function is calculated for each of these regions individually.

The drawback of the original adaptive histogram equalization method is choosing the optimal size of regions. In the most cases, it depends on the type of the input image. Therefore, we propose to use CLANE on every disjoint block with different sizes (8 by 8, 16 by 16, 32 by 32 and, i.e.) in moving windows.

Histogram mapping is a more generalised version of histogram equalization which allows us to specify the shape of the histogram that we wish the processed image to have [12]. The method used to generate a processed image that has a specified histogram is called histogram matching or histogram specification.

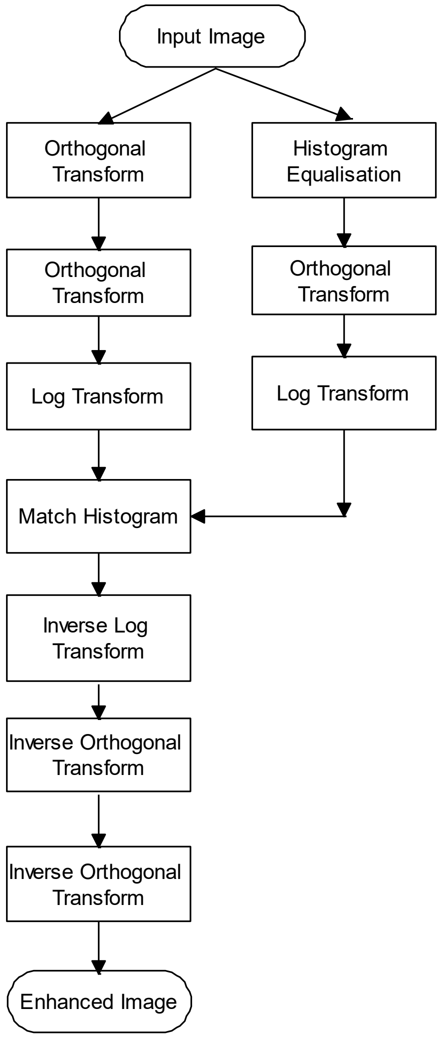

Fig. 3. Block diagram of the enhancement processing.

This method includes three steps:

1) Histogram equalize the original image.

2) Histogram equalize the output image.

Histogram equalization $G(z)$ calculates by the following equation $G(z) = \int_0^z p_z(t)dt$ ·

3) The inverse of the second transform to the original equalized image.

For histogram equalization $G(z)$ should be equal to $T(r)$, i.e.

$$z = G^{-1}[T(r)].$$

Step 3 – EME calculation.

There are several methods introduced as a measure of image enhancement [13]. To measure the quality (or contrast) of images and select the optimal processing parameters, we use the following quantitative measure of image enhancement proposed in [12]. The EME is image enhancement measure introduced by Agaian:

$$EME_{k_1,k_2} = \max\left(\frac{1}{k_1 \cdot k_2}\sum_{l=1}^{k_1}\sum_{k=1}^{k_2} 20 \cdot \log\frac{X^{\omega}_{\max;k,l}}{X^{\omega}_{\min;k,l}}\right)$$

where $X^{\omega}_{\max;k,l}$ and $X^{\omega}_{\min;k,l}$ respectively are the minimum and maximum of the image $x(n,m)$ inside the block $\omega_{k,l}$.

We calculate *EME* for every enhanced image:

- for enhanced image 1 (all image) is $EME^{\tilde{X}1}$;
- for enhanced image 2 (blocks 8 by 8) is $EME^{\tilde{X}2}$;
- for enhanced image 3 (blocks 16 by 16) is $EME^{\tilde{X}3}$;
- for enhanced image 4 (blocks 32 by 32) is $EME^{\tilde{X}4}$.

These values allow to calculate weights, as follow:

$$W^{\tilde{X}1} = \frac{EME^{\tilde{X}1}}{EME^{\tilde{X}1}+EME^{\tilde{X}2}+EME^{\tilde{X}3}+EME^{\tilde{X}4}};$$

$$W^{\tilde{X}2} = \frac{EME^{\tilde{X}2}}{EME^{\tilde{X}1}+EME^{\tilde{X}2}+EME^{\tilde{X}3}+EME^{\tilde{X}4}};$$

$$W^{\tilde{X}3} = \frac{EME^{\tilde{X}3}}{EME^{\tilde{X}1}+EME^{\tilde{X}2}+EME^{\tilde{X}3}+EME^{\tilde{X}4}};$$

$$W^{\tilde{X}4} = \frac{EME^{\tilde{X}4}}{EME^{\tilde{X}1}+EME^{\tilde{X}2}+EME^{\tilde{X}3}+EME^{\tilde{X}4}}.$$

Step 4 – Weighted Average.

The resulted enhanced images define as:

$$\tilde{X} = \tilde{X}1 \cdot W^{\tilde{X}1} + \tilde{X}2 \cdot W^{\tilde{X}2} + \tilde{X}3 \cdot W^{\tilde{X}3} + \tilde{X}4 \cdot W^{\tilde{X}4}.$$

Output – Enhanced Image.

III. EXPERIMENT RESULTS

In this section, we compare our results with well-known algorithms histogram equalization and CLAHE. The dataset contains 100 underwater sequences.

Figures 4-7 demonstrate the underwater image enhancement results obtained by various algorithms respectively (a – original image; b - the enhanced image by the histogram equalization; c - the enhanced image by the CLAHE; d - the enhanced image by the proposed method). The results achieved by current proposed scheme have visually more contrast.

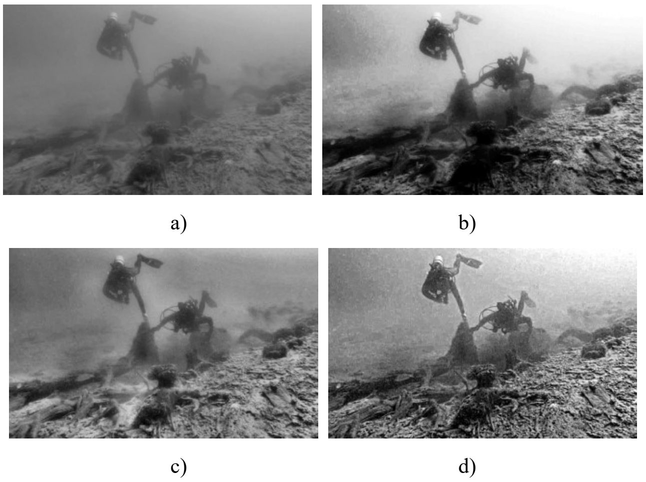

Fig. 4. Underwater Image Enhancement.

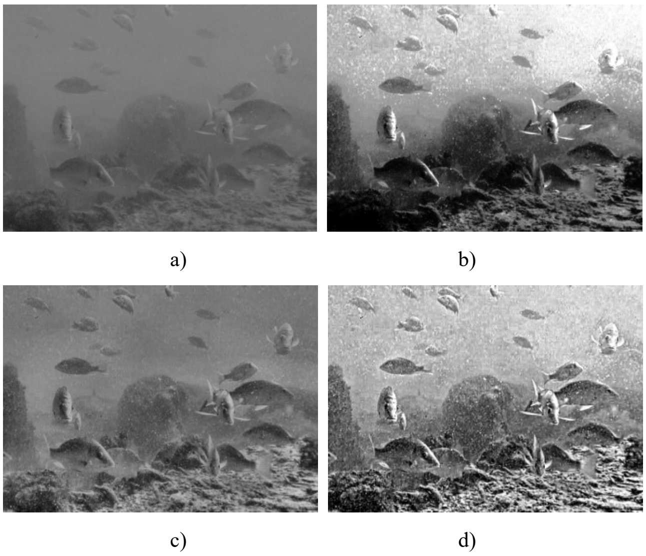

Fig. 5. Underwater Image Enhancement.

Proposed approach shows more details in the obtained enhanced underwater images. The analysis shows, what the proposed method gives better visual quality than histogram equalization technique and CLANE.

The experimental results (Table 1) show that the original images have the lowest EME. After applying proposed local and global processing, the EME has risen. It is noticeable that the quality of the obtained results by the proposed algorithm has several times better in regard to the EME measurement.

The results with EME for different methods can be found in Table 1.

TABLE I. COMPARISON OF RESULTING EME'S OF DIFFERENT ENHANCEMENT METHODS

Images	*Original*	*Histogram equalization*	*CLAHE*	*Proposed method*
Image 1	2,93	13,59	6,66	**29,15**
Image 2	4,36	19,77	9,76	**39,34**
Image 3	4,65	24,92	17,92	**31,93**
Image 4	9,07	11,87	9,94	**54,59**

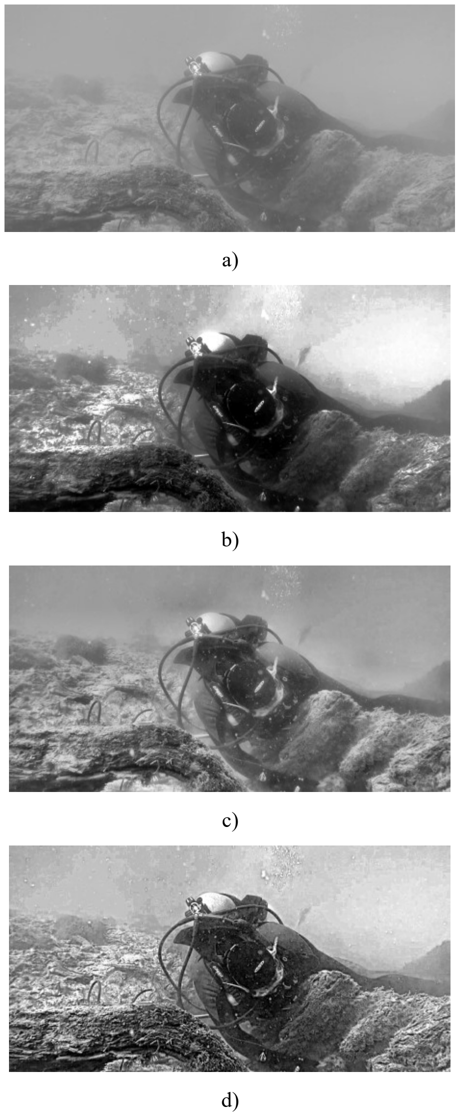

Fig. 6. Underwater Image Enhancement.

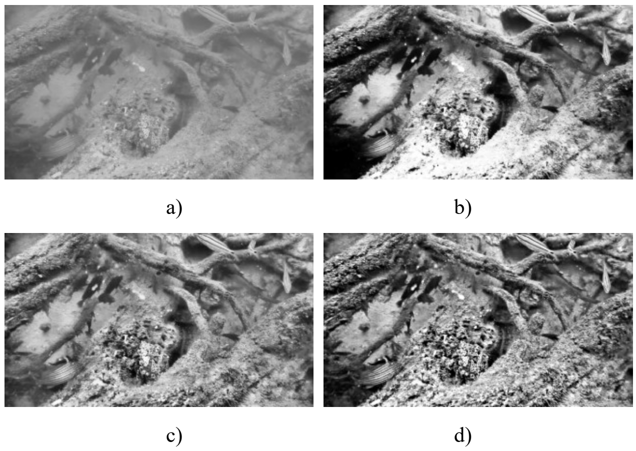

Fig. 7. Underwater Image Enhancement.

IV. CONCLUSION

We present novel enhancement technique based on a new application of contrast limited adaptive histograms on transform domain coefficients called logarithmic transform coefficient adaptive histogram equalization with local and global processing. This strategy for image enhancement allows getting more contrast and detailed underwater image with the following properties: irregular lighting and brightness gradient. Comprehensive validation experiments performed on real underwater images reveal that the proposed method performs better than the current state-of-the-art.

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