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Underwater Image Denoising and Enhancement using Multiscale Product Thresholding and Weber's Law

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Abstract: In a recent year, it is difficult for the researchers to remove noise from the original signal as well as to enhance the quality of the image. However light scattering and color change problems still exist in the underwater image. Scattering problem is affected due to the large suspended particles, which generally leads to the degradation of the image. Color change problem is affected due to the different wavelengths are attenuated to different degrees in water, causing ambient underwater environments to be dominated by a bluish tone. This paper implements a novel method based on multiscale product thresholding and weber's law in order to denoise and enhance the underwater image quality. In this, the proposed scheme is applied to RGB color and grayscale underwater images. The complete image processing is done using MATLAB simulation model.

Keywords: Noise, Weber's law, Multiscale product thresholding etc.

I. INTRODUCTION

The quality of underwater image is different with it in the air area. The two main problems which arise in underwater images are light scattering i.e. which changes the direction of light path and color change. Absorption and scattering are the two basic process of light propagation in the water. The process of the light in the water can influence the overall performance of underwater imaging system. The eminence of underwater images plays a crucial role in scientific missions such as monitoring sea life, taking census of populations and assessing geological or biological environments. Capturing the images in underwater is difficult, mostly due to haze caused by light that is reflected from a surface and is deflected and scattered by water particles. Because of varying degrees of attenuation encountered by different wavelengths of light, underwater images always dominated by a bluish tone. Thus the light scattering and color change result in contrast loss and color deviation in images acquired underwater.

An image is often corrupted by noise in its acquisition and transmission. Image denoising is used to remove the additive noise while preserving the important signal features and not altering the quality of the processed image. Image enhancement improves the visibility of the image. Light scattering and color change can be corrected by enhancing the contrast and image denoising techniques. In the recent years there has been a fair amount of research on wavelet thresholding and threshold selection for signal de-noising because wavelet provides an appropriate basis for separating noisy signal from the image signal. The motivation is that as the wavelet transform is good at energy compaction, the small coefficients are more likely due to noise and large coefficient due to important signal features. These small coefficients can be thresholded without affecting the significant features of the image. In this paper, a near optimal threshold estimation technique for image denoising is proposed which is subband dependent i.e. the parameters for computing the threshold are estimated from the observed data, one set for each subband. The objectives of the proposed work are to develop a qualitative approach to produce a more visually pleasing image. Also to simulate a model for underwater image denoising in order to improve the performance and for underwater image enhancement [1].

II. LITERATURE REVIEW

R. Sathya, M. Bharathi and G. Dhivyasri [2] presented a Dark channel prior method which is used for removing the haze present in the underwater image. This approach is based on a local patches in haze-free underwater images contain some pixels which have very low intensities in at least one color channel. By means of this prior with the haze imaging color model estimates the thickness of the haze and recovers a high quality haze free image. This method does not require images with different exposure values. This technique is completely based on the attenuation experienced by point across multiple frames.

LeiFei, Wang Yingying [3] presented a technique for the crisis of underwater image denoising. This method based on adaptive wavelet combining adaptive threshold selection with adaptive threshold selection with adaptive output of the threshold function. In this, first taking into consideration the underwater image with low signal to noise ratio (SNR), contrast imbalance and poor image quality. After this the next step is some pre-processing

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should be done before wavelet threshold denoising. Then, they adopt adaptive wavelet combining adaptive threshold selection with adaptive output of the threshold function for the image de-noising. Finally the simulation results show that this proposed method not only removes noise effectively, improves image output peak signal-to-noise ratio (PSNR), but also yields superior vision quality and embodies the superiority of wavelet denoising.
Yiwen Liu, Lingling Li, cuihua Li [7] proposes a denoising method based on wavelet threshold and subband enhancement method for image de-noising. This method uses soft threshold method for the minimum scale wavelet coefficients, takes further decomposing for other wavelet coefficient and takes effective enhancement and mixing threshold processing for each subband after being decomposed. Thus making full use of high frequency information of each of the multi-dimension can add image details and get a better enhancement and de-noising effectively. Huimin Lu, Seiichi Serikawa [10] presents a method for underwater scene enhancement using weighted guided median filter. This method includes an effective underwater scene enhancement scheme and a shallow water imaging model that compensates for the attenuation discrepancy along the propagation path. The improved images are characterized by a reduced noised level, better exposure of the dark regions, and superior global contrast where the finest details and edges are enhanced significantly.
Wan Nural Jawahir Hj Wan Yussof, Muhammad Suzuri Hitam, Ezmahamrul Afreen Awalludin, and Zainuddin Bachok [11] presented a Histogram equalization (HE) method. This method is of contrast adjustment using the images histogram and also works for to enhance a given image. In this method, transformation T is to be considered in such a way that the gray value in the output is equally distributed in [0, 1]. It is also called histogram flattening.

III. PROPOSED WORK

In this, the proposed scheme designs the architecture for to denoise and enhance the underwater image. The image denoising algorithm achieves near optimal soft thresholding in the wavelet domain for recovering original signal from the noisy one. During the wavelet denoising, the most important steps are the choices of an appropriate threshold and effective threshold function, which have direct impacts on the performance of a wavelet denoising algorithm. The key of the wavelet threshold de-noising is the relation between wavelet coefficient and threshold. The choice of the threshold determines the coefficient of the wavelet reconstruction. So the selection of adaptive wavelet threshold will help to achieve better de-noising effect.

To achieve an enhancement of the underwater image our proposed scheme uses a method which is based on Weber's law. Weber's law is used to enhance the contrast of an image. In this a method to enhance contrast is proposed; the methodology consists in solving an optimization problem that maximizes the average local contrast of an image. The optimization formulation includes a perceptual constraint derived directly from human threshold contrast sensitivity function. Here it applies the proposed operators to some images with poor lighting with good results. On the other hand a methodology to enhance contrast based on color statistics from a training set of images which look visually appealing is presented. In this way, even though the reported algorithms to compensate changes in lighting are varied, some are more adequate than others.

3.1 Methodology:

The proposed scheme uses multiscale product thresholding algorithm for to denoise the image whereas weber's law is used to enhance the quality of image.
Here the preprocessing, noise estimation and threshold selection includes multiscale product thresholding algorithm.

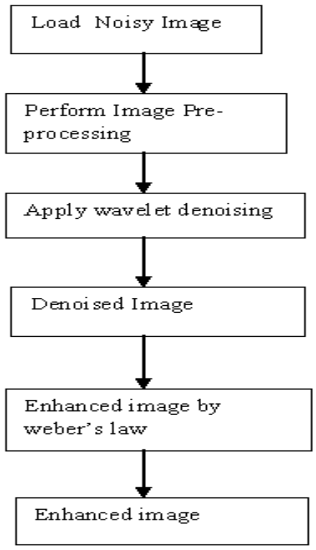

Fig. 1: Steps of image denoising and enhancement

- **Multiscale product thresholding algorithm:**

It contains the following steps:

1. Perform image pre-processing on the image with noise: In order to achieve better de-noising effect, some pre-processing should be done before wavelet threshold de-nosing. The purpose of pre-processing is to reduce the illumination changes, sharpen the edge details, preserve details and eliminate the noise in the image and also resize the image into a standard matlab format. It is used to smooth textures and reduce artifact by deleting small image features amplified by filtering. In this two step filtering techniques are used which are given as follows:

a) Homomorphic filtering:
Homomorphic filtering is a generalized technique for image enhancement and/or correction. It simultaneously normalizes the brightness across an image and increases contrast. If the image model is based on illumination-reflectance, then frequency domain procedures are not as easy to perform. The main reason is that illumination and reflectance components of the model are not separable. To

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be able to improve appearance of an image by simultaneous brightness range compression and contrast enhancement it is necessary to separate two components.
An image can be modeled mathematically in terms of illumination and reflectance as follow:

$$f(x,y) = I(x,y)\, r(x,y) \quad (1)$$

But as we know that,
To accomplish separability, first map the model to natural log domain and then take the Fourier transform of it.

$$z(x, y) = \ln\{ f (x, y)\}$$
$$= \ln\{i(x, y)\}+ \ln\{r(x, y)\} \quad (2)$$

Then,

$$Z(u, v) = I (u, v) + R(u, v) \quad (3)$$

Now, if we process Z(u,v) by means of a filter function H(u,v) then,

$$S(u,v) = H(u,v)I(u,v)+H(u,v)R(u,v)$$

Taking inverse Fourier transform of S(u,v) brings the result back into natural log domain,

$$s(x,y)=F^{-1}\{H(u,v)I(u,v)\}+F^{-1}\{H(u,v)R(u,v)\} \quad (4)$$

By letting,

$$i'(x,y) = F^{-1}\{H(u,v)\, I(u,v)\} \quad \text{and}$$
$$r'(x,y) = F^{-1}\{H(u,v)\, R(u,v)\} \quad (5)$$

Now, to get back to spatial domain, we need to get inverse transform of natural log, which is exponential,

$$s(x,y) = i'(x,y) + r'(x,y) \quad (6)$$
$$g(x,y) = \exp[s(x,y)]$$
$$= \exp[i'(x, y)] \,.\, \exp[r'(x,y)]$$
$$= i_o(x, y)\, r_o(x, y) \quad (7)$$

Where $i_o(x, y)$ is illumination and $r_o(x, y)$ is reflectance components of the output image. This method is based on a special case of a class of systems known as homomorphic systems.
The block diagram for homomorphic filtering is as follows:

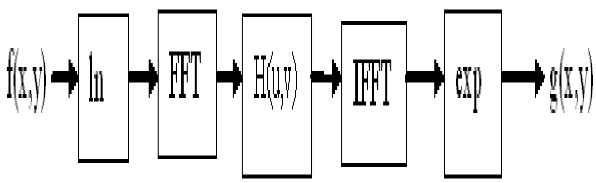

Fig 2: Process of Homomorphic filtering

b) Gaussian low pass filtering:
Gaussian filtering is used to blur images and remove noise and detail. The Gaussian filter is a non-uniform low pass filter. Gaussian filtering is more effective at smoothing images. It has its basis in the human visual perception system. It has been found that neurons create a similar filter when processing visual images. The Gaussian filter work by using the 2D distribution as a point-spread function. This is achieved by convolving the 2D Gaussian distribution function with the image. We need to produce a discrete approximation to the Gaussian function. This theoretically requires an infinitely large convolution kernel, as the Gaussian distribution is non-zero everywhere.

2. Estimate the noise variance: In this the proposed scheme performs discrete wavelet transformation (DWT) which decomposes the noisy image into different frequency sub bands, labeled as LLj, LHk, HLk and HHk, where k=1, 2,...,j. The implementation of 2D discrete wavelet decomposition is shown in Fig.3. The subscript denotes the k-th frequency level and j is the largest scale in the decomposition. Perform Multiscale decomposition of the image corrupted by Gaussian noise using wavelet transform. These all sub bands represent different information about the image. The lowest frequency band LLj represents to a coarse approximation of the image. The LHk, HLk and HHk sub bands represents to the horizontal, vertical and diagonal information of the image signal, respectively. The highest frequency band is HHk. The LLk sub band is further decomposed in recursive manner into the sub bands LHk+1, HLk+1 and HHk+1. From the sub bands it computes noisy part from the band. In this, to compute noise we use the median estimator. For this it uses the following equation [3]:

$$\sigma_v^2 = \frac{\text{median } |HH1|}{0.6745} \quad (8)$$

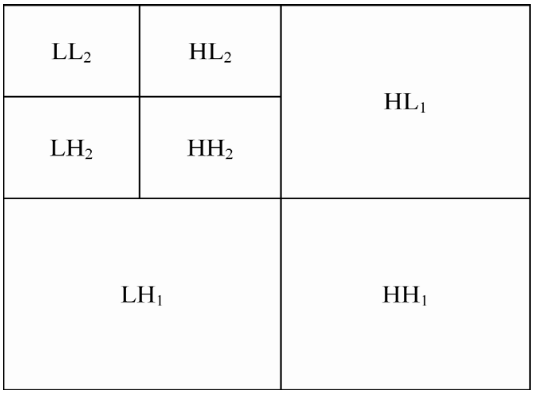

Fig 3: 2D-DWT with 2-Level decomposition

3. Compute threshold selection for to denoise the image. The key of the wavelet threshold de-noising is the relation between wavelet coefficient and threshold. The choice of the threshold determines the coefficient of the wavelet reconstruction. The most difficult problem in wavelet based denoising approach is to find out the exact value of the threshold. In order to realize the adaptive threshold selection, using the formula (9) to select the optimal threshold [3]:

$$\lambda_{MBS} = \begin{cases} \frac{\beta\sigma_v^2}{\sigma_x^2} & \text{if } \sigma_v^2 > \sigma_y^2 \\ \max|A_m| & \text{otherwise} \end{cases} \quad (9)$$

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Where, $\beta = \sqrt{\frac{\log M}{2\times j}}$, M is the total of coefficients of wavelet, j is the wavelet decomposition level present in the subband coefficients, $\sigma_y^2$is the variance of the degraded image after wavelet transform, σ_x^2 is variance of the original image after wavelet transform, and σ_v^2denotes the variance of the noise components after wavelet transform. Where,[3]

$$\sigma_v^2 + \sigma_x^2 = \sigma_y^2 \quad (10)$$

A small threshold can keep the maximum portion of coefficients related to the noisy signal and that results a signal which is still noisy. And when the threshold is a large value will shrink maximum portion of coefficients. That results blurring of the signal which causes losing of important textures in the image. So the selection of adaptive wavelet threshold will help to achieve better de-noising effect. Finally at last shrinks all the coefficients using bivariate shrinkage method.

4. Obtain a denoise image
Following figure shows the block diagram of image denoising:

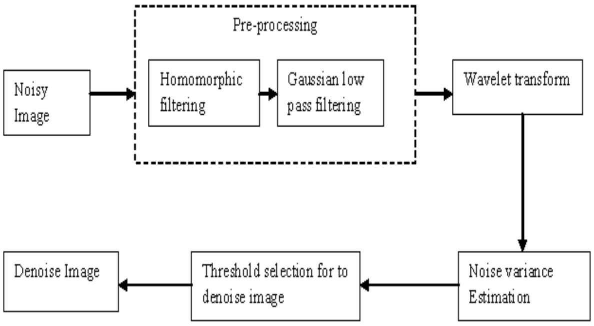

Fig 4: The process of Image denoising

- **Weber's Law:**

In the proposed scheme, the enhancement of the image is based on the weber's law. This technique enhances the contrast of an image effectively. This law has a logarithmic relation. Weber's law states that the relationship between the physical stimuli and the perceived intensity of the stimuli is logarithmic. The threshold for detecting an increment in the quantity or intensity of something, changes depending on how much there is before we add the increment. Weber's law is a hypothesis about how this threshold change happens.
Weber's law can be best understood from the following example. Consider a photo taken in a dark room. The obtained photo actually consists of 2 different things. One is what we visually perceive in that image and the other is what is actually present in that image. Weber's law simply states that the relation between these two is logarithmic.
In image acquisition, background detection is necessary in many applications to get clear and useful information from an image which may have been picturized in different conditions like poor lighting or bright lighting, moving or still etc. This part deals with background analysis of the image by blocks. In this, D represent the digital space under study, with D = Z *Z and Z and Z is the integer set. For each analyzed block, maximum (M_i) and minimum (m_i) values are used to determine the background measures. τ_i is used to select the background parameters. Background parameters lie between clear ($f > \tau_i$) and dark ($f \le \tau_i$) intensity levels. If ($f \le \tau_i$) is the dark region then background parameters takes the maximum intensity levels (M_i) then ($f > \tau_i$) is the clear region, background parameters takes the minimum intensity levels (m_i). Enhance images are we get after applying the below equation.
τ_i was substituted by $\tau(x)$, since has a local character given by the structuring element. In this way, the contrast operator as [13]

$$\tau_{\tau(x)}(f) = \begin{cases} k_{\tau(x)} \log(f+1) + \delta_x(f)(x), & f \le \tau(x) \\ k_{\tau(x)} \log(f+1) + \varepsilon_x(f)(x), & \text{otherwise} \end{cases} \quad (11)$$

and

$$k_{\tau(x)} = \frac{255 - \tau(x)}{\log(256)} \quad (12)$$

δ_x- Dilation operation, ε_x- Erosion operation
Dilation and erosion are the two most common morphological operations used for back ground analysis by blocks.
The following Fig. 5 shows the process of image enhancement.

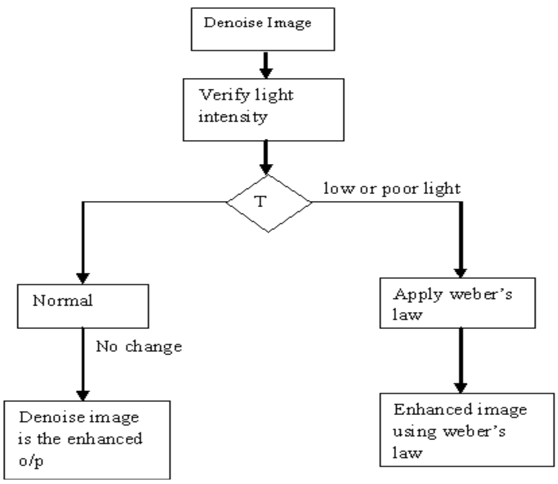

Fig 5. The process of image enhancement

3.2 Performance Metrics:

The four parameters are used for the performance evaluation of underwater images are as follows:
1. MSE: The Mean Square Error (MSE) represents the cumulative squared error between the compressed and the original image. The lower the value of MSE, the lower the error. The MSE is computed by using the following equation:

$$MSE = \frac{\sum_{M,N}[I_1(m,n) - I_2(m,n)]^2}{M*N} \quad (13)$$

2. RMSE: The Root Mean Square Error (RMSE) (also called the root mean square deviation, RMSD) is a

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frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modelled. These individual differences are also called residuals, and the RMSE serves to aggregate them them into a single measure of predictive power.

$$\text{RMSE} = \sqrt{\text{MSE}(\widehat{\emptyset})} = \sqrt{\text{E}(\widehat{\emptyset} - \emptyset)^2} \qquad (14)$$

3. PSNR: Compute peak signal-to-noise ratio (PSNR) between images. This ratio is often used as a quality measurement between the original and a compressed image. The higher the PSNR, the better the quality of the compressed, or reconstructed image.

$$\text{PSNR} = 10 \ \log_{10}\left(\frac{R^2}{\text{MSE}}\right) \qquad (15)$$

Where,
R is the maximum fluctuation in the input image data type
4. Correlation: Compute the correlation coefficient between an image and filtered image. Digital image correlation is an optical method that employs tracking and image registration techniques for accurate 2D and 3D measurements of changes in images.

3.3 Experimental Results and Discussion:

The performance of the multiscale product thresholding algorithm and weber's law is evaluated for underwater images using MATLAB 2-D function. These can be used for image denoising and enhancement. We have evaluated the performance of the proposed scheme using metrics such as MSE, RMSE, PSNR and Correlation etc. The images taken as an input are shown below. Then these images are taken into a standard format of the MATLAB. The proposed scheme is applied on RGB color and gray scale images. In fig 6 (a) shows noisy underwater image, then the pre-processing such as homomorphic filtering and gaussian low pass filtering is applied to this noisy underwater image. Fig 6 (b) shows denoised image by applying wavelet denoising method and fig 6 (c) represents the enhanced image if there is need after denoising. In this, weber's law is used for the enhancement purpose as it is a morphological operation. The similar results are evaluated on other input images which is shown in Fig. 7. In Fig. 7 the proposed scheme is applied to grayscale underwater images. Fig. 7 (a) underwater grayscale input image (b) denoise image (c) enhanced image and (d) input and output histogram of the image.

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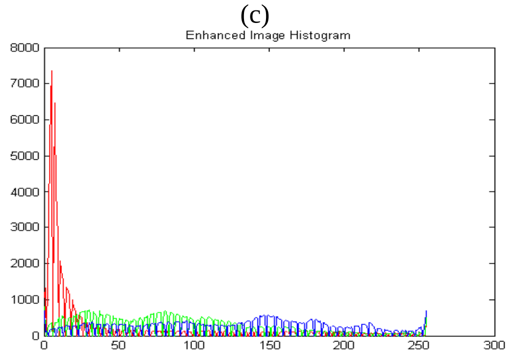
(a)

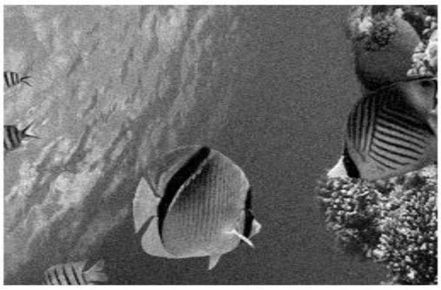
(b)

(c)



(d)

Fig 6: Results on RGB color image (a) Underwater image with noise (b) Denoise Image (c) Enhanced Image (d) Enhanced image histogram



(a)

(b)

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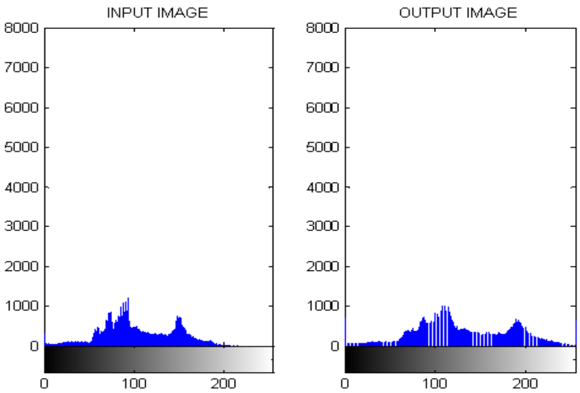
(c)



(d)

Fig 7: Results on gray scale image (a) Underwater image with noise (b) Denoise Image (c) Enhanced Image (d) Input-Output image histogram

Following table shows the parameter analysis using our proposed scheme. Our proposed scheme yields a better result than the other methods.

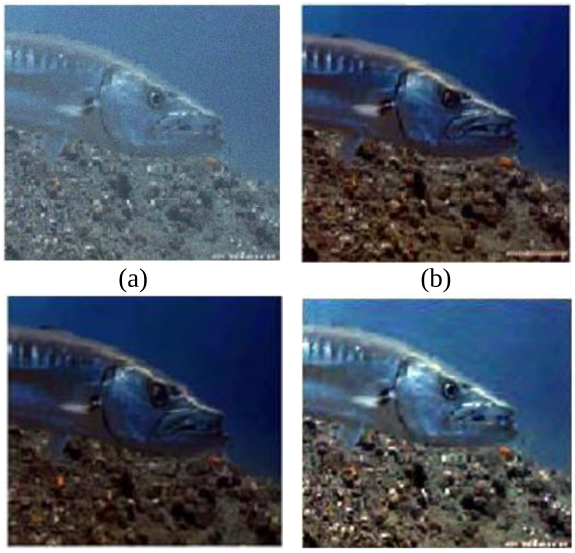
Table 1: Parameter Analysis using proposed approach

	MSE	RMSE	PSNR	Correlation
Underwater RGB color Image 1	33.8836	2.4127	65.6618	0.9936
Underwater gray scale Image 2	21.9907	2.1655	69.4848	0.9869

Next, we compare our proposed method with the existing method Dark channel prior and Histogram equalization method.

We compare the results using PSNR which is shown in the following Table 2. As from this analysis the performance of the proposed scheme is better than the Dark channel prior and Histogram equalization method.

Following Fig 8 shows results of different methods (a) Input Underwater noisy image (b) By Dark channel prior (c) By Histogram equalization (d) By our method.



(a) (b) (c) (d)

Fig 8: Results of different methods (a) Input Underwater noisy image (b) By Dark channel prior (c) By Histogram equalization (d) By our method

Table 2: Comparative Analysis of Different Methods

For Underwater Image 8	PSNR
Dark Channel Prior	48.7065dB
Histogram Equalization	22.2872dB
Our method	68.9419 dB

IV. CONCLUSION

At present, scientists are eager to explore the underwater world. However, the area is still lacking in image processing analysis and methods that could be used to improve the quality of underwater images. Underwater image denoising and enhancement techniques provide a way to improve the object identification in underwater environment. The proposed algorithm not only removes noise, improve the PSNR, but also get a better visual effect. There is a lot of research started for the improvement of image quality, but limited work has been done in the area of underwater images. As our proposed method is applied on only Grayscale and RGB color images, so the further research will apply on other image types.

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