Underwater Image Enhancement by Wavelet Based Fusion

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***Abstract* - The image captured in water is hazy due to the several effects of the underwater medium. These effects are governed by the suspended particles that lead to absorption and scattering of light during image formation process. The underwater medium is not friendly for imaging data and brings low contrast and fade color issues. Therefore, during any image based exploration and inspection activity, it is essential to enhance the imaging data before going for further processing. This paper presents a wavelet-based fusion method to enhance the hazy underwater images by addressing the low contrast and color alteration issues. The publicly available hazy underwater images are enhanced and analyzed qualitatively with some state of the art methods. The quantitative study of image quality depicts promising results.**

Keywords—Underwater, hazy images, wavelet, fusion, image enhancement

I. INTRODUCTION

At present, the robotic-based exploration and inspection activities are performed in deep Ocean. The underwater imaging is one of the important parts of these robotic based events. The light is attenuated in the underwater environment due to the absorption effects by water molecules, suspended particles and other impurities. The attenuation increases as light travel deeper into the water. During image formation process in such an environment, less irradiance reaches to the camera from the object in the scene that modifies the real colors of the object. The penetration of the visible spectrum colors depends on the depth of water and their wavelength. Longer wavelengths get absorb in water first while shorter wavelengths can last at a longer distance (see Fig. 1). For instance, in seawater the red color starts disappearing first at a depth of about 3 meters. Similarly, orange and yellow disappear at 5 meters and 10 meters respectively [1]. In higher depths, most of the underwater images are dominated by blue or green colors due to their shorter wavelengths.

During light propagation in water, the photons collide with water molecules as well as other particles. This collision changes the direction of photons randomly, and such random change of photons direction governs the scattering phenomenon of light [3]. In most of the images, the forward scattering is responsible for contrast problems. The low contrast limits the visibility in an underwater environment and image formation

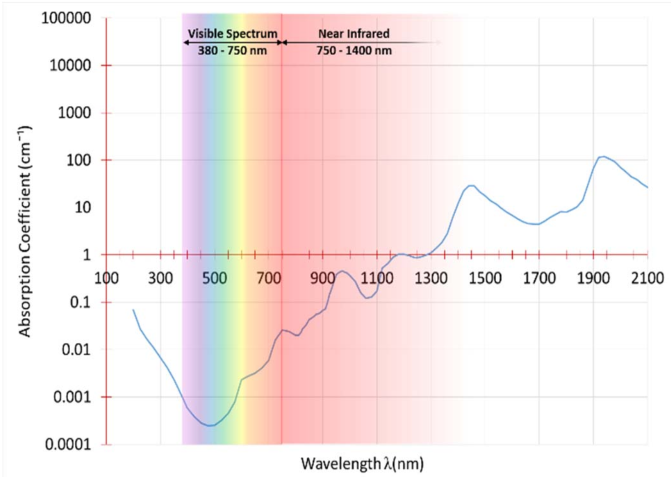


Figure 1: Absorption coefficient of visible light in water [2].

process, the images become darker. The low contrast issue affects the feature extraction process in further image processing procedures. For instance, during a study on the underwater 3D reconstruction of volcano rocks using structure from motion (SFM) for geological research, the authors faced low contrast problems [3]. The less information of depth and cloud points, made it difficult to reconstruct 3D model from the actual scene for computer analysis.

This paper presents a wavelet-based fusion technique to overcome color and contrast issues in underwater images. The remaining sections of the paper are arranged as: Section II explains the wavelet based fusion with subsections: color & contrast enhancement, decomposition, fusion and inverse composition. Section III is dedicated to results and discussion. Finally, the paper is concluded in Section IV.

II. WAVELET-BASED FUSION

In signal and image processing the fusion is used to solve different problems [4]. Our method is based on the fusion of images using discrete wavelet transform [6] for the enhancement of the underwater images. In our proposed method low contrast and color attenuation of the hazy images are addressed. Therefore, we are employing CLAHE [7] and histogram stretching techniques for contrast enhancement and color correction. The complete procedure for wavelet based fusion approach is shown in Fig. 2. Initially, the hazy underwater image is replicated into two versions. These versions are processed in parallel to enhance the image contrast and color profiles. Then, the wavelet-based decomposition, fusion, and inverse composition are performed to obtain the color and contrast enhanced image.

A. Color and Contrast Enhancement

For color correction, the image is converted from RGB (Red-Green-Blue) to HSV (Hue-Saturation-Value) color space.

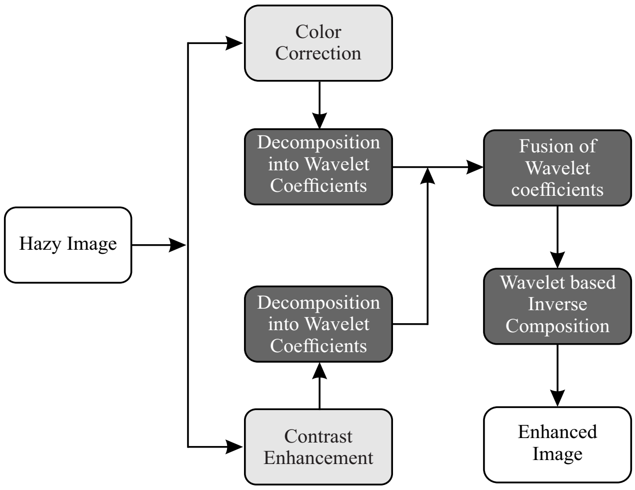


Figure 2: A wavelet based fusion approach for underwater image enhancement

In HSV color space the histogram of the Value component is stretched over the whole range. This operation improves the brightness of the available colors in the image. Then the Hue and Saturation are concatenated with the corrected value component and hence the image is converted back to the RGB color space. In RGB color space, once again the histogram is stretched over the whole range (0 to 255) to achieve the color correction in all three channels. The histogram stretching is based on the mathematical expression given in the Eq. (1).

$$P_{out} = (P_{in} - i_{min})\left(\frac{o_{max} - o_{min}}{i_{max} - i_{min}}\right) + o_{min} \tag{1}$$

where P_{out} and P_{in} are the pixels of output and input images respectively. i_{min}, i_{max} , o_{min} and o_{max} are minimum and maximum values of intensities for input and output images respectively.

To enhance the contrast of the underwater images, we adopted the contrast limited adaptive histogram equalization (CLAHE) [8]. The CLAHE is a variant of adaptive histogram equalization (AHE) [9], [10]. In AHE the noise over-amplification tendency is higher during the contrast enhancement. Therefore, to reduce this problem, the contrast limit is defined in CLAHE to clip the unnecessary region from the histogram [11]. The clipping limit is defined by the normalization of the histogram and thereby the size of the neighborhood region in the pixel domain. The clipping region is not discarded but redistributed equally among all histogram bins as in Fig.3 it can be seen that (blue shaded) bins over the clip region are redistributed. The redistribution will push some of the bins over the defined clip limit again (green shaded region in Fig. 3), this effect can be reduced by repeating the procedure recursively until the excessive area is negligible. The CLAHE is applied to all three color channels in RGB color space separately to enhance the contrast of all available tints in the image.

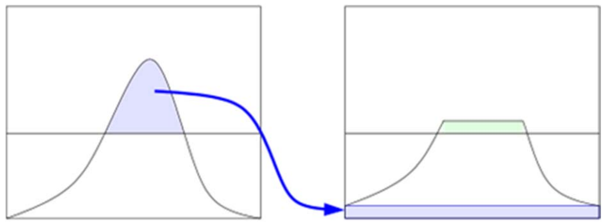


Figure 3: Redistribution of histogram in CLAHE

B. Decomposition, Fusion and Inverse Composition

The wavelet based fusion algorithm consists of a sequence of low pass and high pass filter banks that are used to eliminate unwanted low and high frequencies present in the image and to acquire the detail and approximation coefficients separately for making the fusing process convenient [12].

In Fig. 4, one level, 2- dimensional decomposition of the input image into its detail and approximation coefficients is described. Each input image is filtered and down-sampled by a factor of 2. The factor of 2 in the algorithm is used to divide the information contained in the input signal into two equal parts at each step of filtering so that the information can be analyzed deeply. In this scope of the study, we are using two levels of decomposition, but in Fig. 4, only one level decomposition is shown. There are two steps in level one; the first step is achieved by applying the low pass and high pass filters with down-sampling on the rows of the input image *x(r, c)*. This generates horizontal approximations and horizontal details respectively. In the next step, the columns in the horizontal coefficients are filtered and down-sampled into four sub-images [13]: Approximate (LL), Vertical detail (LH), Horizontal detail (HL), and the Diagonal detail (HH) as shown in Fig. 4.

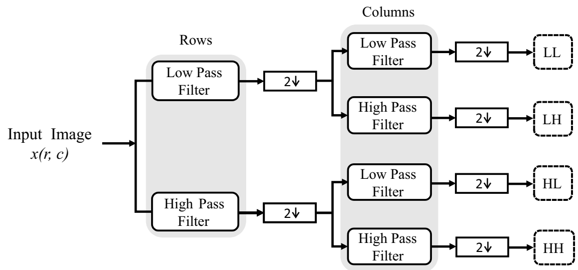


Figure 4: One-level-2D wavelet-based image decomposition

At the second level of decomposition, the decomposed approximate image (LL) of the first level becomes the input image and the process is repeated to scale down coefficients as shown in Fig. 4. Each input image is decomposed into its wavelet coefficients by using the procedure as described above. In our case both enhanced images: the color corrected and the contrast enhanced versions of the input image are decomposed into their wavelet coefficients then both decompositions are fused by using coefficients of maximum values as shown in Fig. 5 [4].

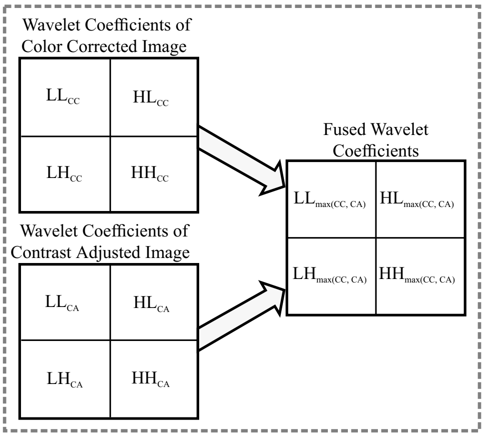


Figure 5: - Fusion of one level decomposed wavelet coefficients

After combining coefficients of both enhanced images into fused coefficients, the inverse composition is applied to get the synthesized image. For the inverse composition, the reverse process is carried out with the help of up-sampling and filtering steps using filter banks to get a synthesized or enhanced image *y(r, c)*, see Fig. 6. Since we are dealing with discrete data sets

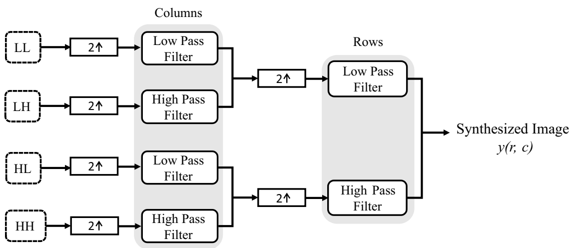


Figure 6:- One-level-2D wavelet-based inverse composition

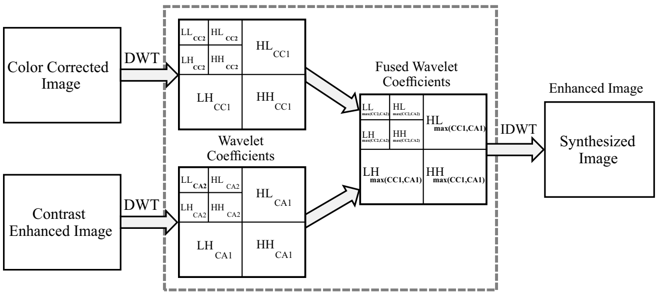


Figure 7: Two-level-2D decomposition, fusion of coefficients and image synthesizing

so in digital image processing, each input image is decomposed into its coefficients and inversely composed into a synthesized image by using discrete wavelet transform (DWT) and Inverse discrete wavelet transform (IDWT) respectively. In Fig. 7, a complete picture of two level discrete wavelet-based decompositions, fusion and inverse composition of enhanced image is shown.

III. RESULTS AND DISCUSSION

The publicly available hazy underwater images downloadable at [14] by [5], [15]–[18] are used for enhancement using proposed method. The full reference quality metric is used for the image quality evaluation. Following eight images are chosen for evaluation of the proposed method as shown in Fig 8.

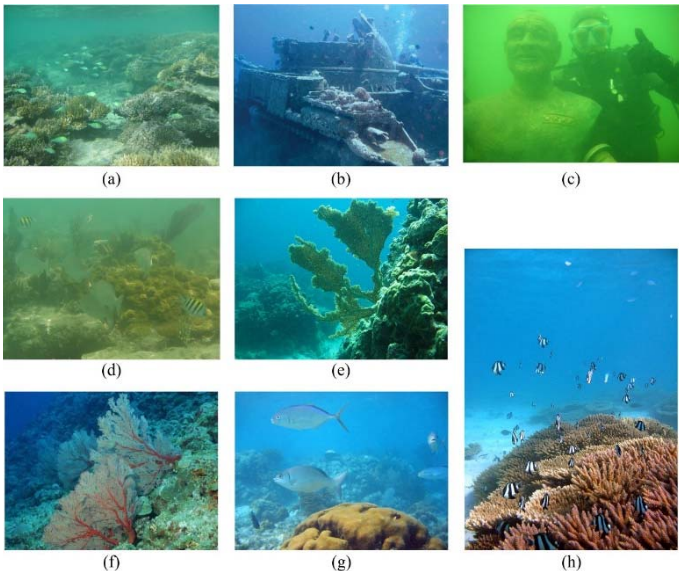


Figure 8:- The set of hazy underwater images chosen for evaluation and named (a) through (h) as Image 1 to Image 8.

To evaluate the method quantitatively, four statistical quantities are calculated that include: Root Mean Squared Error (RMSE), Peak Signal to Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM) and Measure of Entropy (MoE). The enhanced images are also compared qualitatively with state of the art image enhancement methods[15]–[18].

The comparison of the enhanced images with some available sate of the art methods is shown in Fig. 9 through Fig. 12. From the results, it can be analyzed that the color and contrast of the hazy images are enhanced. The proposed method also improves the visibility of the images with a wider field of view such as in Image 1 and Image 8 (see Fig. 9 and Fig. 12). In underwater, the color profile of the image is easily attenuated due to light absorption effects in water. Those colors that have shorter wavelengths can survive at longer distances. That is the reason most of the underwater images have blue or green dominated color.

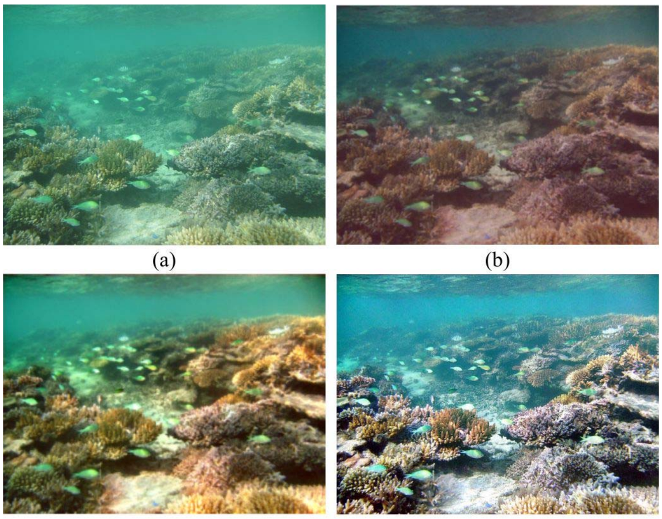


Figure 9:- Results on (a) hazy underwater Image 1: Comparison with (b) [17] (c) [16] and (d) Wavelet based Fusion

Green color dominates the Image 3 in the evaluated set of images. In the results, it can be observed that the natural color profiles of Image 3 is preserved by correcting the dominated color and it was hard before to distinguish the color of the water and objects in the scene as shown in Fig. 11. The quantitative study of the selected image set is in shown in Table 1. In this study, the lower values of RMSE and higher values of PSNR, SSIM and MoE represent the better performance of the proposed method. In SSIM and RMSE profiles, Image 3 and Image 4 only show lower values in SSIM and higher values in RMSE, while rest of the images in evaluation process show improved quality.

Table 1: Quantitative Evaluation of the images in Fig. 7: values of RMSE, PSNR, SSIM, MoE

	Statistical Quantity				
	RMSE	PSNR	SSIM	Entropy Comparison	
				[a]MoE $_{hazy}$	[b]MoE $_{enhanced}$
Image 1	433.33	28.01	0.70	7.31	7.83
Image 2	531.32	27.80	0.59	7.79	7.89
Image 3	1331.13	23.25	0.30	7.60	7.88
Image 4	1638.23	22.66	0.23	7.37	7.83
Image 5	419.72	28.65	0.76	7.55	7.65
Image 6	723.94	26.06	0.66	7.42	7.90
Image 7	304.83	30.28	0.85	7.81	7.83
Image 8	345.37	28.82	0.88	7.68	7.83

[a]MoE $_{hazy}$ = Measure of Entropy on hazy Image
[b]MoE $_{enhanced}$ = Measure of Entropy on Enhanced Image

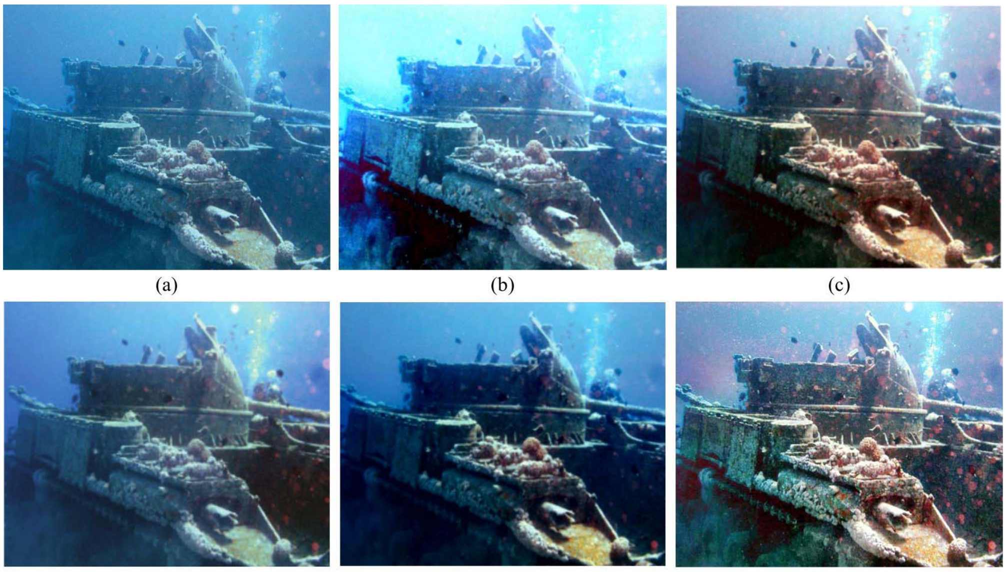
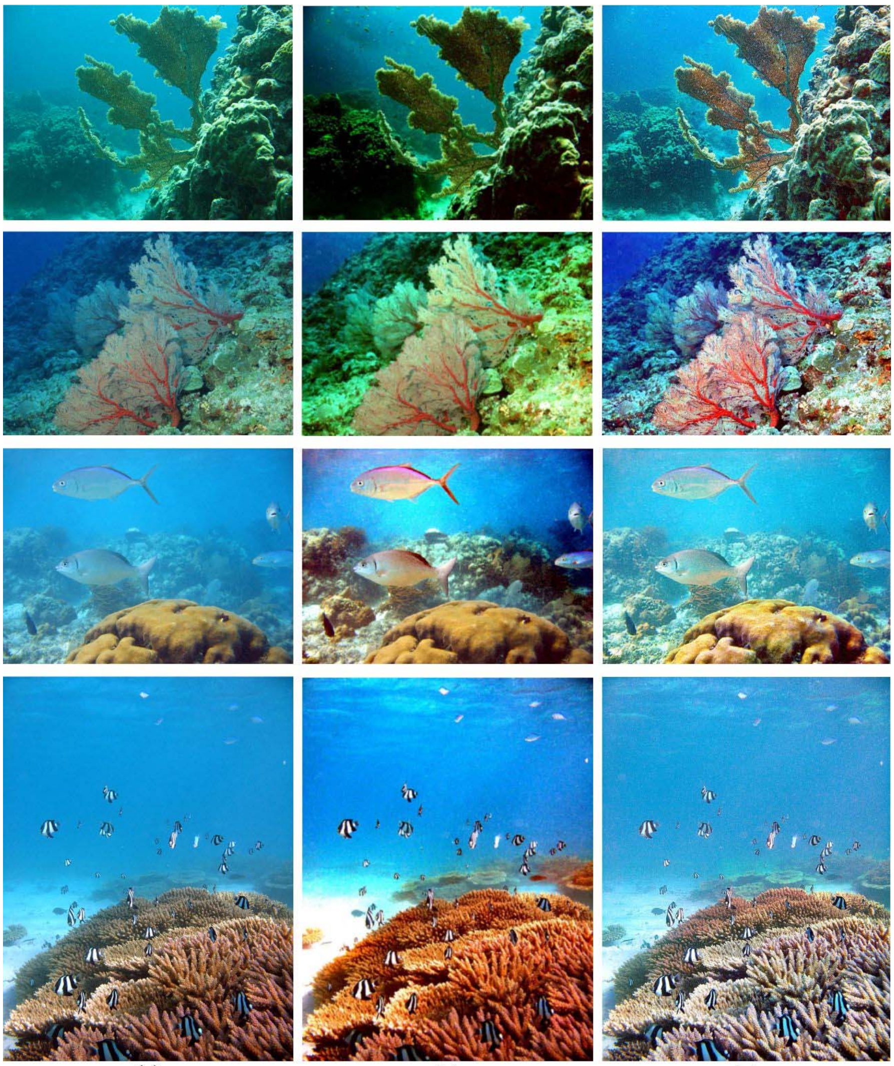


Figure 10:- Results on (a) hazy underwater Image 2: Comparison with (b) [18] (c) [17] (d) [15] (e) [16] and (f) Wavelet based Fusion

(a) (b) (c)

Figure 11:- Results on (a) hazy underwater Image 3 and Image 4(from top to bottom): Comparison with (b) [17] and (c) Wavelet based Fusion.



(a) (b) (c)

Figure 12:- Results on (a) hazy underwater Image 5, Image 6, Image 7 and Image 8 (from top to bottom): Comparison with (b) [18] and (c) Wavelet based Fusion.

IV. CONCLUSION

In this paper, the hazy underwater images have been enhanced in term of color and contrast using wavelet-based fusion approach. The qualitative results depict that the proposed method has enhanced the quality of the hazy underwater images. The quantitative analysis shows the quality of the image is also maintained. In future, a comprehensive comparative study will be performed on state of the art methods for quantitative analysis with the proposed method.

ACKNOWLEDGMENT

The authors would like to acknowledge that this research is funded by Universiti Teknologi PETRONAS under Yayasan UTP Grant scheme (0153AA-E52).

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