Multimed Tools Appl (2018) 77:4309–4322
https://doi.org/10.1007/s11042-017-5187-7

Color fidelity and visibility enhancement of underwater image de-hazing by enhanced fuzzy intensification operator

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Received: 3 July 2017 / Revised: 13 August 2017 / Accepted: 30 August 2017 /
Published online: 5 December 2017

Abstract This paper presents an optimization based algorithm for underwater image de-hazing problem. Underwater image de-hazing is the most prominent area in research. Underwater images are corrupted due to absorption and scattering. With the effect of that, underwater images have the limitation of low visibility, low color and poor natural appearance. To avoid the mentioned problems, Enhanced fuzzy intensification method is proposed. For each color channel, enhanced fuzzy membership function is derived. Second, the correction of fuzzy based pixel intensification is carried out for each channel to remove haze and to enhance visibility and color. The post processing of fuzzy histogram equalization is implemented for red channel alone when the captured image is having highest value of red channel pixel values. The proposed method provides better results in terms maximum entropy and PSNR with minimum MSE with very minimum computational time compared to existing methodologies.

Keywords Underwater image · Enhancement · Color fidelity · Fuzzy intensification · Visibility

1 Introduction

Due to the physical properties of underwater environment, capturing an image in underwater is the big challenging task [21]. While capturing an image in underwater, due to the light absorption and scattering property and also water molecules are reacted with the light to produce an image with low color, diffusion and loss of contrast. It is called image hazing effect [3]. Image de-hazing [22] is the process of removing hazing effect in an image or reconstructed into natural appearance. The blue

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light travels very long distance in underwater optical imaging compared to green and red light. Due to that, the underwater images are visualized as bluish in color. Underwater vision plays an important role in Navy applications involving marine engineering, mine detection, diver visibility and search. The capability to perceive better precision and farther object has always been a central goal of underwater imaging. Therefore, an effective method which can enhance underwater images for both display and analysis is meaningful, and thus desired. Figure 1 shows a color appearance in underwater. According to the characteristic of underwater optical imaging, the blue light travels the longest distance in the water due to its shortest wavelength, followed by the green light and then the red light. The bluish and greenish effect is considered as one of the blur. In the proposed method, there is no separation of background to remove the haze and enhancement. The adaptive fuzzy membership function is derived for each color channel based on the minimum and maximum pixel intensities in the underwater color image. The derived membership function is used to set the threshold value for control parameter used in the fuzzy intensification operator. Naturally, fuzzy intensification operator is applied to improve the color and contrast. Due to fuzzy membership function, the uncertainty for information loss is reduced.

The post processing enhancement steps are not necessary in the proposed algorithm. The result shows that the natural color appearance and better visibility and contrast enhancement compared to previous methods. The main contribution of this paper is to remove haze by which color and contrast is improved. The separate preprocessing or post processing to improve color and contrast is not necessary in the proposed method. The computational time is very low compared to existing methodologies. The rest of the paper is organized in the following manner.

The section 2 describes about literature survey of underwater image de-hazing. The section 3 illustrates about the proposed methodology includes adaptive fuzzy intensification operator method. The section 4 deals about comparative result analysis of proposed method with the existing methodologies. This paper is concluding with section 5 describing about conclusion and future enhancement.

2 Literature survey

An image based processing technique is applied with the combination of four filters to remove the haze effect in an image [20]. The shallow underwater image enhancement technique [10] is used to remove the haze effect and to improve the visibility, color of an underwater image. In this technique, histogram equalization, gamma correction and dark channel prior with morphological operations are applied to remove the haze effect. It also eliminates halo effect with single image de-hazing. Single

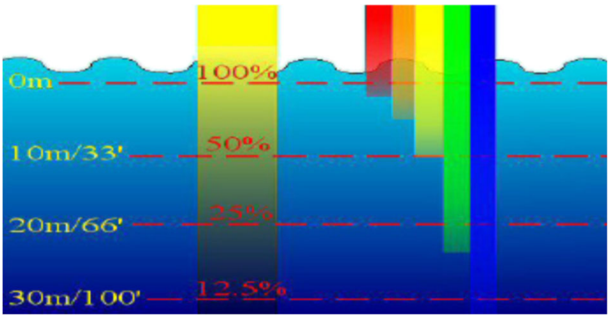

Fig. 1 Color appearance in underwater

underwater image restoration [13] by green and blue channel de-hazing and red channel correction algorithm is proposed. The image contrast, color and visibility are improved while reducing the light saturation and scattering characteristics. The mixture contrast limited adaptive histogram equalization [12] is proposed to remove haze in an underwater image by improving visibility and dropping noise and artifacts. For estimating the scattering rate and an effective method for underwater image enhancement, a new underwater dark channel [23] is derived to estimate the background light in the underwater optical model. The scattering rate and transmission estimation of light is computed by which image enhancement is achieved. An effective underwater image color cast removal algorithm [14] is presented based on the optimization theory. The minimum information loss and inherent relationship of medium transmission maps of three color channels in an underwater image is derived using visibility restoration algorithm. It is used to recover visibility, contrast, and natural appearance of degraded underwater images. The bright channel prior of underwater environment [9] is proposed for restoring and enhancing underwater images. For estimating and rectifying the bright channel image, atmospheric light and refining the transmittance image, restoration algorithm is proposed. For color correction and equalizing the histogram distribution, deduced histogram equalization is proposed. A fuzzy based technique [19] called dark channel prior and fuzzy enhancement based method is applied to remove haze from a hazy image. The color correction is done by fuzzy based histogram equalization to reduce the artifacts and amplification of noise. An optimum fuzzy system [11] is proposed to minimizing fuzzy entropy by which the underwater image contrast and visual perception are improved. In order to improve color fidelity and visibility, fuzzy intensification is the best approach. The fuzzy logic procedure is used to reduce the uncertainty in the prediction of haze affected image pixel values and correctly predicting pixels for color correction through which color and contrast is improved with minimum information loss. The fuzzy intensification operator is basically used for improving color and contrast in image enhancement technique. It is a simple scheme to implement image enhancement. The fuzzy intensification based underwater image enhancement technique [1] is available in the literature. The non-fuzzy based and fuzzy based techniques are available [7, 18] and [4–6, 8, 15, 16] in literature for image enhanmcement through image dehazing.

2.1 Contribution

1. The modification in fuzzy intensification membership function is proposed in this paper to handle underwater image de-hazing and enhancement.
2. There are two scenarios handled in the proposed technique. In first scenario, the enhanced fuzzy intensification membership function itself is used to enhance the output and restore the hazed underwater image. In second scenario, fuzzy histogram equalization is applied to enhance the restored image.

3 Enhanced fuzzy intensification operator for underwater image de-hazing (EFIO)

3.1 Computation of enhanced fuzzy intensification operator

In the proposed technique, the underwater image is captured and it is represented in RGB color model. For implementing fuzzy intensification operator, the control parameter is computed [1]. After control parameter computation, fuzzy intensification operator is computed for each

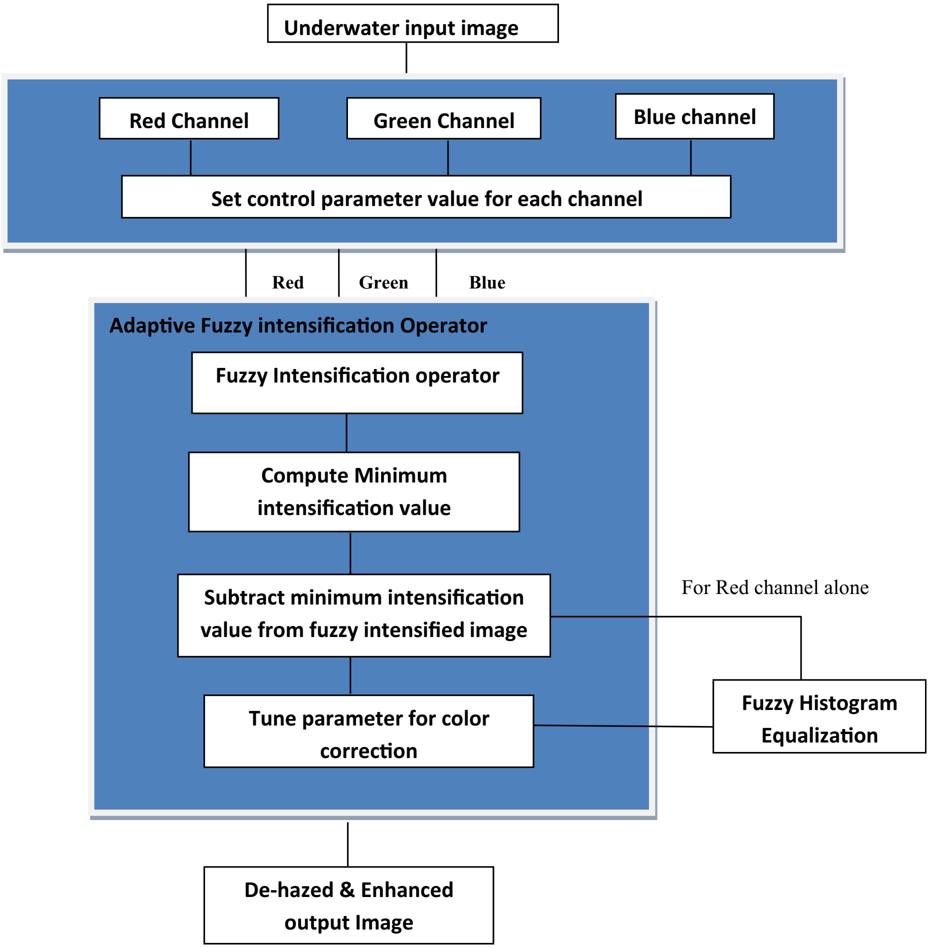

Fig. 2 Representation of proposed Enhanced Fuzzy intensification operator

channel separately. In the proposed methodology, while computing membership function of fuzzy intensification operator, the modification is carried out (Fig. 2).

For RGB color channel, the membership function is computed by the following formulae [1],

$$\mu_r = \frac{r - min(r)}{max(r) - min(r)} \tag{1}$$

$$\mu_g = \frac{g - min(g)}{max(g) - min(g)} \tag{2}$$

$$\mu_b = \frac{b - min(b)}{max(b) - min(b)} \tag{3}$$

By introducing enhanced fuzzy intensification, the above formulae are modified by calculating minimum intensification value in the proposed method.

$$\mu'_r = \mu_r - \left[\min\left(\min(r)\right)\right] \tag{4}$$

$$\mu'_g = \mu_g - \left[\min\left(\min(g)\right)\right] \tag{5}$$

$$\mu'_b = \mu_b - \left[\min\left(\min(b)\right)\right] \tag{6}$$

The Enhanced fuzzy intensification membership function is used to improve the color and contrast without implementing image enhancement techniques. The Enhanced fuzzy intensification operators are calculated by the following formulae

$$AF_r = \begin{cases} 2^*\left(\mu_r'(x,y)\right)^2 & , if\, \mu_r'(x,y) \le \varphi_r \\ 1-2^*\left(\mu_r'(x,y)\right)^2 & , otherwise \end{cases} \tag{7}$$

$$AF_g = \begin{cases} 2^*\left(\mu_g'(x,y)\right)^2 & , if\, \mu_g'(x,y) \le \varphi_g \\ 1-2^*\left(\mu_g'(x,y)\right)^2 & , otherwise \end{cases} \tag{8}$$

$$AF_b = \begin{cases} 2^*\left(\mu_b'(x,y)\right)^2 & , if\, \mu_b'(x,y) \le \varphi_b \\ 1-2^*\left(\mu_b'(x,y)\right)^2 & , otherwise \end{cases} \tag{9}$$

$\boldsymbol{\varphi_r}$, $\boldsymbol{\varphi_g}$ and $\boldsymbol{\varphi_b}$ are control parameters which is used for processing of image pixels. AF_r, AF_g, AF_b are represented as enhanced fuzzy intensification operator.

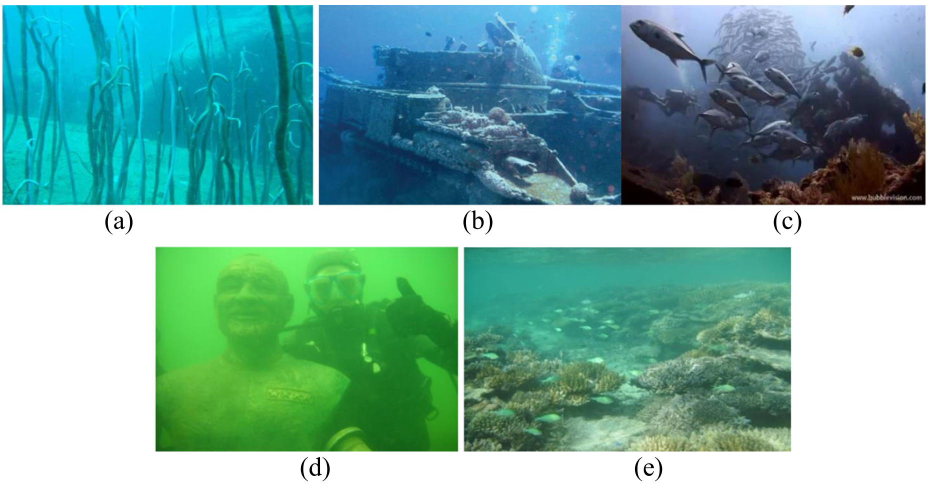

Fig. 3 Underwater Images (**a**) Emberton (**b**) Eustice (**c**) Bali (**d**) Ancuti (**e**) Galdran

(a) (b)

Fig. 4 **a** Fuzzy intensified operator output **b** Enhanced Fuzzy intensified operator of Ancuti Data

(a) (b)

Fig. 5 **a** Fuzzy intensified operatoroutput **b** Enhanced Fuzzy intensified operator of Fattal Data

3.2 Tuning of parameter

The color fidelity of an underwater image is controlled by tuning parameter [1]. The tuning parameter (Ω) is combined with enhanced fuzzy intensification operator to enhance and restore the underwater image. The control parameter value is set based on experimentation. The range of control parameter value is from 0.4 to 0.7 for the red, green and blue channels. The restored and enhanced output is derived by the following equation

$$\psi_{\mathbf{r}} = (AF_r)^{\varphi_r + \Omega} \tag{10}$$

$$\psi_{\mathbf{g}} = \left(AF_g\right)^{\varphi_g + \Omega} \tag{11}$$

$$\psi_{\mathbf{b}} = (AF_b)^{\varphi_b + \Omega} \tag{12}$$

(a) (b)

Fig. 6 **a** Fuzzy intensification operator **b** Enhanced Fuzzy intensification operator of Chiang Data

Fig. 7 **a** Fuzzy intensification operator **b** Enhanced Fuzzy intensification operator of Gladran Data

Fig. 8 **a** Fuzzy intesnsified operator **b** Enhanced Fuzzy intensified operator of Emberton Data

Table 1 PSNR, MSE and entropy comparison of ancuti, fiattal, chiang, gladran and emberton database images

Database	Ancuti1	Ancuti2	Ancuti3	Ancuti4	Ancuti5
PSNR	39.08	38.82	37.23	38.08	39.17
MSE	439.12	443.78	456.37	445.23	429.24
Entropy	7.6	7.5	7.4	7.5	7.6
SSIM	0.72	0.77	0.73	0.74	0.72
Database	Faittal1	Faittal2	Faittal3	Faittal4	Faittal5
PSNR	42.45	42.01	41.89	41.78	43.01
MSE	380.23	381.11	397.67	399.45	377.67
Entropy	8.4	8.5	8.3	8.4	8.6
SSIM	0.83	0.81	0.8	0.81	0.82
Database	Chiang1	Chiang2	Chiang3	Chiang4	Chiang5
PSNR	42.75	41.78	42.02	41.45	42.21
MSE	379.21	398.11	381.11	391.11	381.02
Entropy	8.4	8.	8.4	8.3	8.4
SSIM	0.8	0.81	0.81	0.8	0.81
Database	Gladran1	Gladran2	Gladran3	Gladran4	Gladran5
PSNR	37.89	36.78	36.92	37.45	37.81
MSE	454.17	467.34	465.12	452.17	452.01
Entropy	7.1	7.3	7	7.1	7.6
SSIM	0.73	0.71	0.72	0.74	0.73
Database	Emberton1	Emberton2	Emberton3	Emberton4	Emberton5
PSNR	39.23	38.45	39.12	38.78	39.05
MSE	441.25	452.23	441.29	460.23	442.12
Entropy	7.1	7	7.2	7.3	7.1
SSIM	0.76	0.74	0.74	0.75	0.75

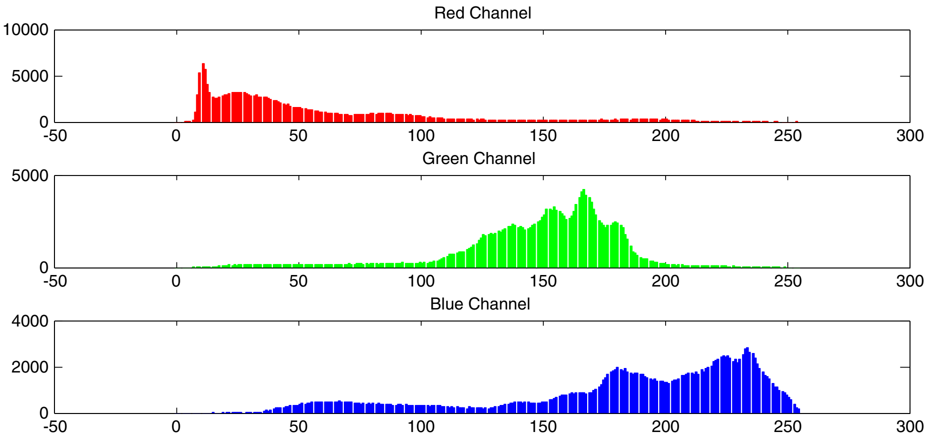

Fig. 9 Representation color histogram before dehazing of fish fattal image

3.3 Fuzzy histogram equalization

The fuzzy histogram [17] of an image is computed using enhanced fuzzy intensification operator. In first scenario of proposed technique, the captured underwater image pixels are having highest value of green and blue channel, the histogram equalization is not necessary. In case of second scenario, the captured underwater image pixels are having highest value of red channel pixels values; the fuzzy histogram equalization is applied. After computing enhanced fuzzy membership function by eq. (7) the fuzzy histogram is computed to improve the contrast and color. The fuzzy histogram is computed using the following formulae

$$F = h(i) + \sum_i \sum_j AF_{c,} \ c \in r \tag{13}$$

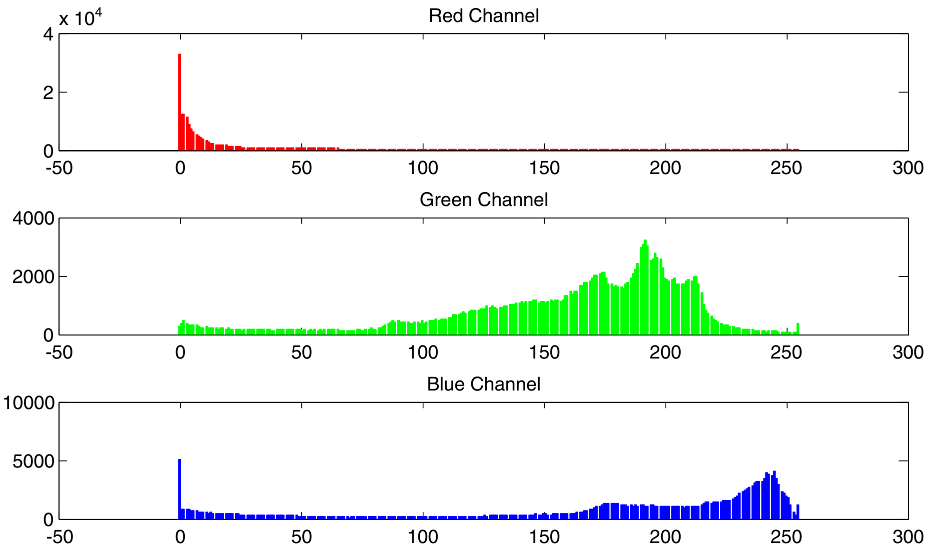

Fig. 10 Representation of color histogram After dehazing of fish fattal image

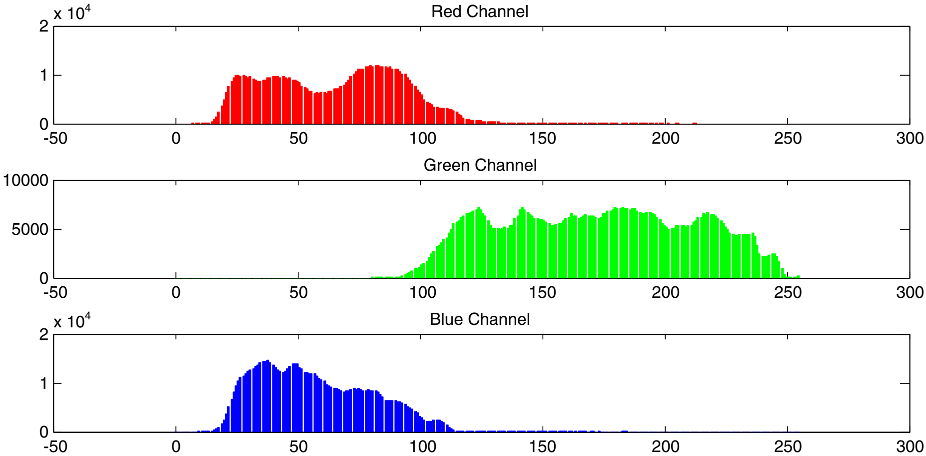

Fig. 11 Color histogram of man ancuti image before dehazing

h(i) is the sequence of real numbers or frequency of occurrence of gray level 'i' and i∈ 0…L-1. From [2], in conventional histogram equalization, remapping of histogram peaks leads to introducing blocking artifacts in the images. In order to avoid the blocking artifacts and uncertainty for mapping histogram peaks fuzzy histogram is used. Compared to three channels, the information loss is more in red channel. Due to that the fuzzy histogram equalization is done for red channel alone. The brightness and contrast are improved automatically when visibility and fidelity is improved.

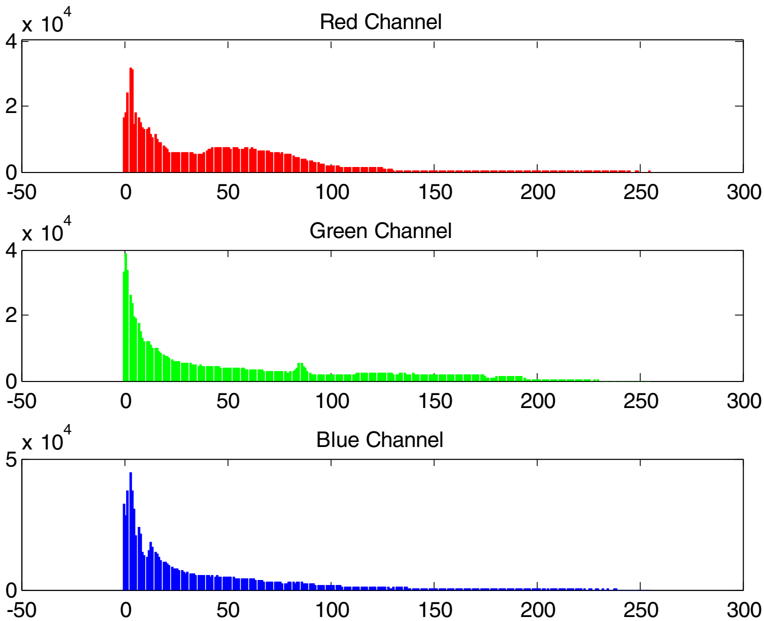

Fig. 12 Color hostogram of man ancuti image after dehazing

Table 2 Comparison of PSNR, MSE and entropy values of proposed method with existing methods

Method	PSNR (db)	MSE	Entropy	Computational Time (s)	SSIM
Four filter	42.37	387.13	7	17.24	0.7
Shallow underwater	23.45	745.68	5	21.45	0.4
Single underwater	24.67	697.67	6	22.12	0.5
CLAHE	31.35	463.28	6.5	18.45	0.6
Optical model	34.24	423.19	6.5	19.12	0.6
Optimization theory	42.41	376.89	7.5	45	0.75
Bright channel prior	33.21	456.32	6	18.24	0.7
Fuzzy histogram	40.12	400.13	7	17.23	0.7
Optimum fuzzy histogram	42.23	389.34	7.5	23.12	0.8
Proposed EFIO	43.17	377.21	8.5	10.2	0.85

4 Results and discussion

The experimental results are obtained using five underwater image dataset. The experiment was conducted using the Ancuti, Fattal, Chiang, Emberton and Gladran dataset with MATLAB R2012a of intel core 2 duo processor and 2GB RAM and 320 GB hard disk capacity. The computational time and performance metrics PSNR, MSE, Entropy are compared with the existing techniques. The main advantage of the proposed technique is minimum computational time with higher PSNR and Entropy values (Figs. 3, 4, 5, 6, 7, and 8).

The above Table 1 compares PSNR, MSE and Entropy value of the proposed enhanced fuzzy intensification operator for underwater image dehazing. The image color fidelity is measured using structural similarity index measure (SSIM). The proposed method shows higher value of SSIM for the databases used in this paper. From the comparison, the PSNR and Entropy values are increased when the underwater images are having hgihre values of blue and green channel pixela values. The 4db to 5 db of differnce in PSNR when the red channel pixel values are higher. When compared to PSNR and Entropy values with visual perception, the proposed method provides higher visual perception for both two scenarios handled in the proposed tehcniques (Figs. 9, 10, 11, and 12).

From the Table 2, the performance metrics of PSNR, MSE values are analyzed and compared. The Entropy and SSIM are the performance measure for the visual perception

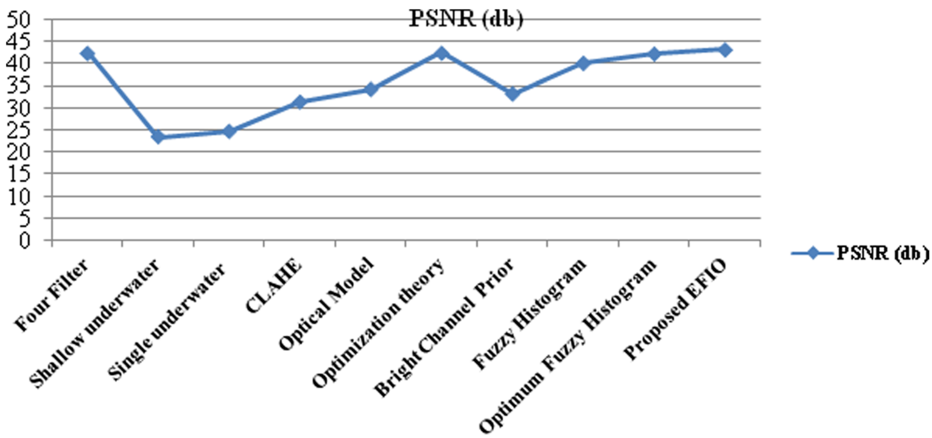

Fig. 13 Comparison of PSNR with existing methods and proposed method

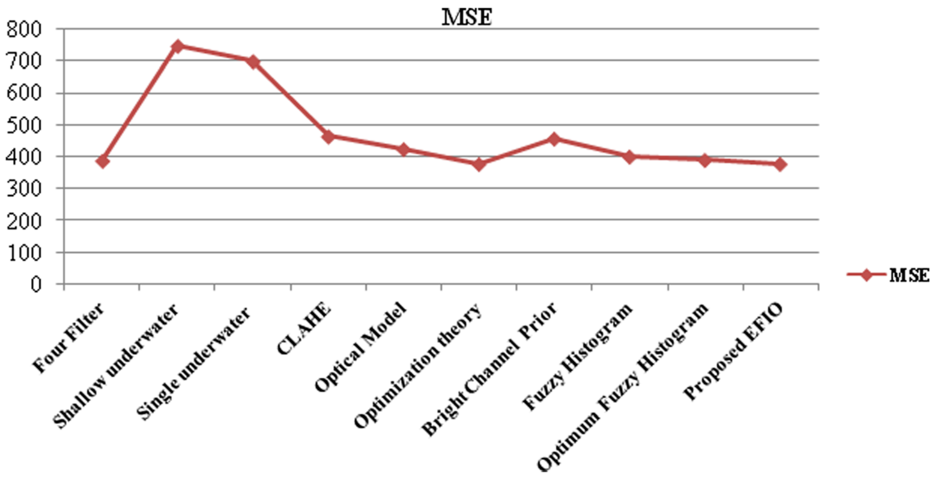

Fig. 14 Comparison of MSE with existing methods and proposed method

and color fidelity. The color fidelity of the proposed method is increased when compared to existing methods discussed in the literature [1, 9, 11–14, 19, 23]. The computational time is very low when compared to other existing methods. From the result analysis, the proposed methods provide better results in terms of qualitatively and quantitatively with minimum computational time. In existing work of fuzzy intensification operator [1] is tested with only image captured from dusty weather. The proposed enhanced fuzzy intensification operator is tested with underwater images that are corrupted by haze effect (Figs. 13, 14, 15, and 16).

5 Conclusion and future enhancement

The Enhanced Fuzzy intensification operator provides higher color fidelity measure and visibility measure in the range of 0.9 of SSIM value and above 8.5 entropy value when compared to existing technologies. The use of fuzzy based techniques is to avoid the uncertainty for removing haze and improving color and contrast of gray level image pixels. The proposed method works suitable for

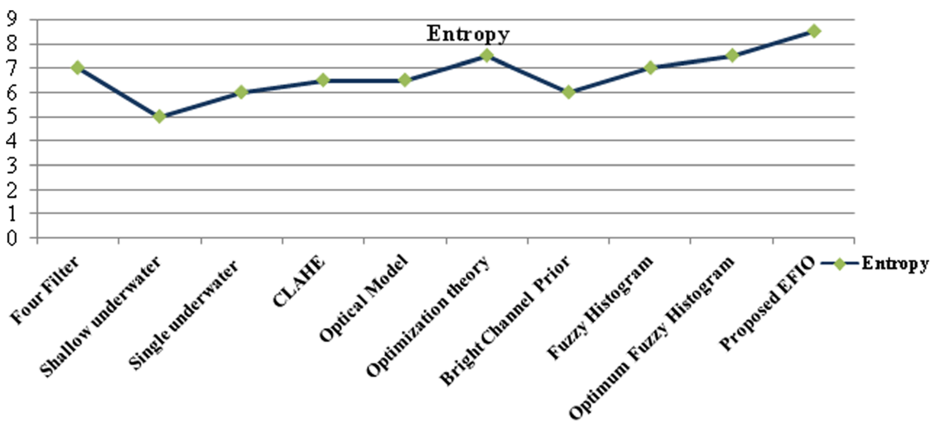

Fig. 15 Comparison of PSNR with existing methods and proposed method

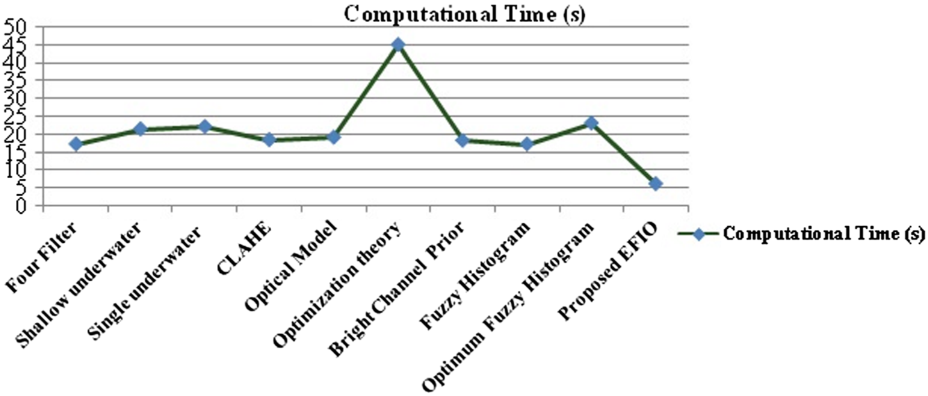

Fig. 16 Comparison of PSNR with existing methods and proposed method

two scenarios of images with higher red channel pixel values and green and blue channel higher values. The enhanced fuzzy intensification itself is adequate to remove the haze and improve the color and visibility. For images having higher red channel pixel values are de-hazed and enhanced by applying fuzzy histogram as post processing. The entropy and structural similarity measure are used as the performance metrics for the visibility and color fidelity improvement in the proposed method. The proposed method works better for removing haze and improving color fidelity and visibility with high value of entropy and SSIM. The proposed work is to be suited for object prediction in video which is considered as a future work.

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