Chapter 1:

Introduction

Underwater imaging is an important area in research and present technology. There are several rare attractions in underwater environment such as amazing landscapes, marine animals and mysterious ship wrecks. Scattering and absorption of light are the major reasons of low contrast and low clarity of underwater images. Absorption considerably reduces light energy and it depends upon many factors such as salinity, turbidity of water etc. Scattering causes deflection of the ray from a straight path due to irregularities in the propagation medium, particles etc. Fading of colors take place due to this. Also the image captured is hazy due to several effects of underwater medium
.

There are many strategies and methods for enhancing and restoring underwater images. Traditional enhancing techniques such as histogram equalizations and gamma correction show various limitations.

Proposed method is an effective approach which is able to remove the haze and enhance image which is clicked by a conventional camera. It fuses two images that are directly derived from the color compensated and white-balances version of the original degraded image. White balancing stage removes undesired color cast induced due to scattering. After this the Multi scale fusion process gives the final improvised image.

Chapter 2:

Image Enhancement Process

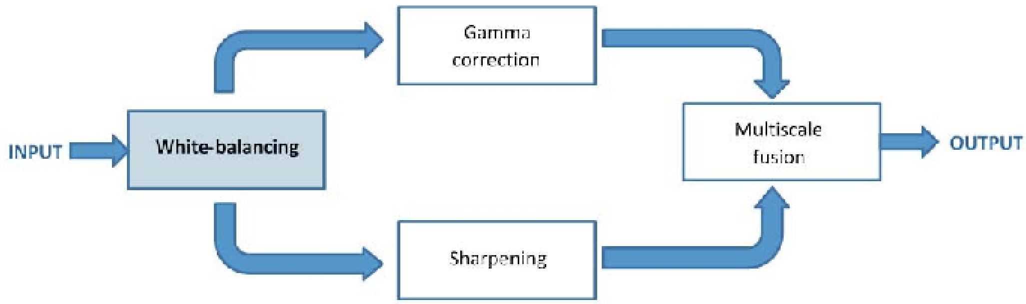

Fig -1 Method overview

It builds on the fusing of two images that are directly derived from color compensated and white-balanced version of the original degraded image. The white balancing stage removes undesired color cast induced by underwater light scattering and produce natural appearance of underwater images. It reduces the quantization artifacts introduced by domain stretching. A well-known white balancing method Gray- World algorithm is used which can achieves good visual performance for reasonably distorted underwater images. The reddish appearance of high intensity regions in the image is also well corrected since the red channel is better compensated.

Multi-scale implementation of fusion is an effective fusion based approach, relying on gamma correction and sharpening to deal with the hazy nature of the white balanced image. The weight maps such as Laplacian contrast weight, saliency weight, saturation weight maps are used during blending in such a way that pixel with a high weight value are more represented in the final output image. It also can enhance the quality of the underwater images. The enhanced image after applying proposed method is given in Fig -2.

Fig -2 Normal v/s Enhanced image

Chapter 3:

Various Approaches

1. Light propagation in underwater:-

Ideally the received light for the transmission is affected due to the target object and the lens of the camera. But this is not the case underwater. It is affected due to several reasons. Some of them are listed below.

a. The amount of light which is available underwater. It depends on various factors such as the interaction between the sun light and sea surface, the interface between air and water etc.
b. The density of the particles which light has to go through. Particle density is hundred times more in seawater than in the normal atmosphere.
c. Refractive index of the water also plays a crucial role.

Total irradiance incident on a point of an image plane has three components in underwater medium.

- **Direct component:-** It is the component reflected by the object onto the image plane. It is given by the equation in equ-1.

$E_D(x) = J(x)e^{-\eta d(x)} = J(x)t(x)$	Equ -1 [1]

- **Forward Scattering:-** It results from the deviation of the light ray on its path to the lens of camera. It can be determined experimentally using a point-spread function which depends on the distance between the image plane and the object.
- **Back Scattering:-** It is due to the artificial light which hits the water particles and gets reflected back to the camera. It can be expressed as depicted in equ-2

$E_{BS}(x) = B_\infty(x)(1 - e^{-\eta d(x)})$	Equ- 2 [1]

So finally the simplified optical model underwater can be represented as shown in equ-3.

$\mathcal{I}(x) = J(x)e^{-\eta d(x)} + B_\infty(x)(1 - e^{-\eta d(x)})$	Equ -3 [1]

2. Related Work :-

The various underwater dehazing techniques are grouped into several classes.

a) Methods using specialized hardware.

Ex: The Divergent-beam underwater Lidar imaging system uses an optical/laser-sensing technique to capture images.

b) Polarization based methods.

This uses several images of an object with different degrees of polarization which is obtained by rotating a polarizing filter which is fixed on the lens of the camera.

c) Multiple images or rough approximation of the scene model.

It includes changing the intensity of the scene under different weather conditions so as to recognize the depth discontinuities in the scene.

d) Based on the similarities between light propagation in fog and under water.

There are several methods introduced for image dehazing and to restore images of outdoor foggy scenes. These methods reconstruct the intrinsic brightness of objects. Several algorithms that restore underwater images are based on Dark Channel Prior. The conventional dark channel prior method removes haze and thus restores colors of objects in the scene, but it does not consider the enhancement of image contrast. On the contrary, the image contrast method improves the local contrast of objects, but the colors are often distorted due to the over-stretching of contrast. The proposed algorithm combines the advantages of these two conventional approaches for keeping the color while dehazing.

These approaches however appear to be effective only for the relatively well illuminated scenes, and generally introduce strong halos and color distortions in presence of relatively poor lightning conditions.

Chapter 4:

Underwater White Balance

As depicted in Fig-1, the complete image enhancement system uses a two-step method

1. White Balancing
2. Image Fusion

White Balancing aims to compensate for the color cast while the image fusion focuses on enhancing the edges and the details of the scene.

White Balancing improves the image aspect by removing the undesired color casting produced in the medium due to its attenuation properties. In underwater the color basically depends on the depth. Major problem which need to be solved is the appearance of greenish-bluish shade in the image which degrades its quality. As it is well known that Scattering attenuates more the longer wavelengths as compared to the short ones, the color recognition gets worsened as we go deeper into the water. Total distance between the observer and the object also plays an important role.

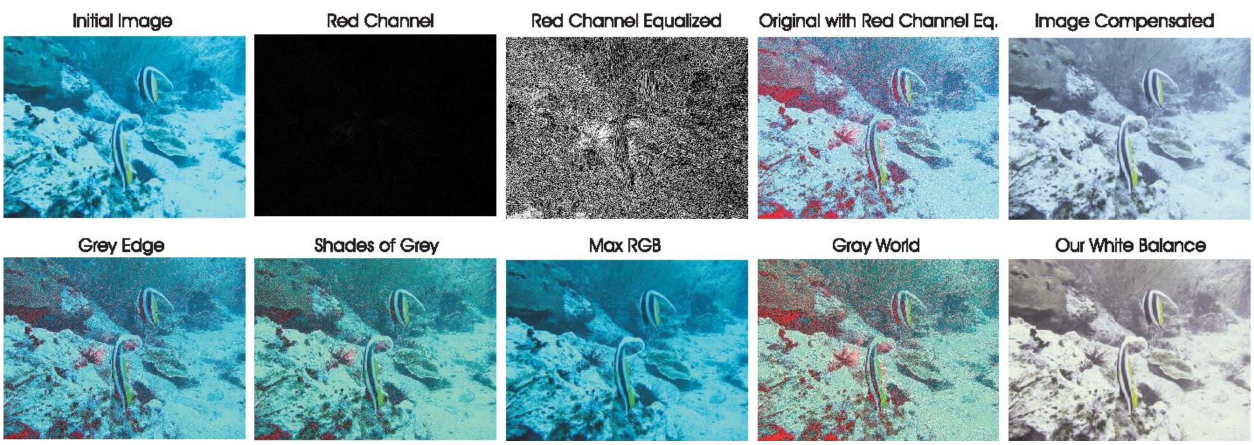

Fig-3

There exists numerous white balancing methods and they've identified number of solutions as well to the problem. Fig-3 displays the effect of different white balancing methods on a single image.

Most of the methods make an assumption to estimate the color of the incident light source, and then achieve color constancy by dividing each color channel in the spectrum with its corresponding normalized light source intensity.

- Gray World method makes an assumption that the average reflectance in the scene is achromatic. So the color distribution is estimated by averaging each channel independently.

- The Max RGB method makes an assumption that maximum response in each channel is due to the white patch and it consequently estimates the color of the light source by using the maximum response of each color channel.
- In the Shades of Grey method it was observed that Max-RGB and Gray-World are two instantiations of the Minkowski p-norm applied to the native pixels.

After the comprehensive study of the various methods it is concluded that the Gray-World method gives good visual performance for reasonably distorted underwater images. But the further research of this method revels that this method is successful in removing the bluish tone significantly but it suffers from severe red artifacts.

To compensate for the loss of red channels, following observations are drawn:-

- Green channel is relatively well preserved under water, compared to the red and the blue ones.
- Green channel contains the opponent color information compared to the red ones ,so is important to compensate for the stronger attenuation induced on red as compared to that on green. So we try to add a fraction of green channel to red.

Fig-4

Fig-4 tries to explain that using only the information of the green channel allows to better recover the entire color spectrum while maintain a natural appearance of the background.

- The obtained compensation should reflect proportionality between the difference of mean green and mean red values.
- To avoid saturation of the red channel, the enhancement of the red should affect the pixels with small red values not the pixels with significant red component. The green channel information should not be transferred to the region where there red is still significant.

Mathematically, the compensated red channel at every pixel location (x) can be represented as shown in Equ -4

$I_{rc}(x) = I_r(x) + \alpha.(\bar{I}_g - \bar{I}_r).(1 - I_r(x)).I_g(x),$	Equ -4 [1]

I_r and I_g represent the red and green color channels of image *I*. α denotes a constant parameter. We consider its value a 1.

In turbid waters or in places with high concentration of plankton, the blue channel may be significantly attenuated due to the absorption of organic matter.

$I_{bc}(x) = I_b(x) + \alpha.(\bar{I}_g - \bar{I}_b).(1 - I_b(x)).I_g(x),$	Equ -5 [1]

I_b and I_g represent the blue and green color channels of image *I*. α denotes a constant parameter. We consider its value a 1.

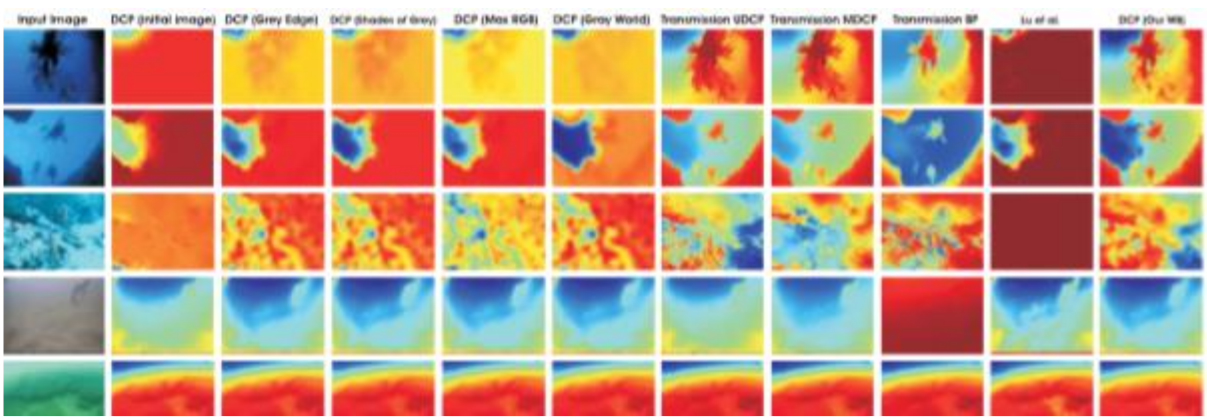

Fig -5

Despite white balancing is crucial to recover the color, this step alone is not sufficient to solve the dehazing problem as the edges and details of the scene get affected due to scattering. So we go on to the next step i.e. Multi-Scale Fusion.

Chapter 5:

Multi-Scale Fusion

Image fusion plays a key role in various applications such as image composting, multi-spectral video enhancement, defogging etc. To use this method we need set of inputs and weight maps derived from single original image. In particular as depicted in Fig- 1, a pair of inputs is introduced to respectively enhance the color contrast and the sharpness of the white-balanced image, and the weight maps are defined to preserve the qualities and reject the defaults of those inputs i.e. to overcome the artifacts induced by the light propagation limitation in underwater medium.

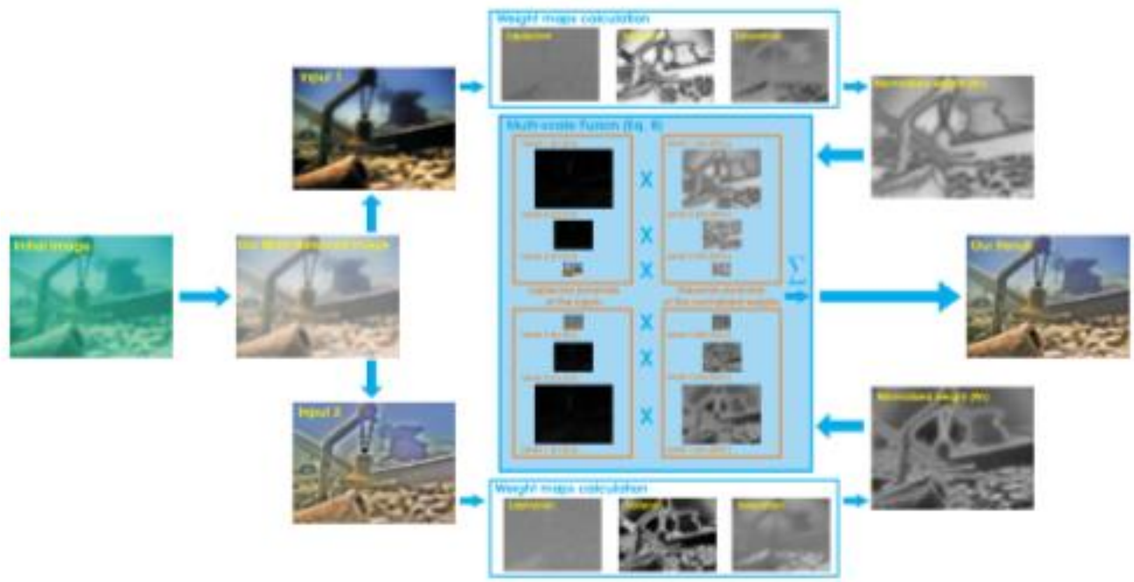

Fig-6

As depicted in Fig-6 , the underwater dehazing technique consists of three main steps:-

- Inputs derivation for the white balanced underwater image
- Weight maps definition
- Multi-scale fusion of the inputs and weight map

A. Inputs of the fusion process

If the depth of the water is more than 30 ft, white balancing suffers from some noticeable effects as it is difficult to regain the absorbed colors. As a result, to get the first input a set of gamma correction technique is applied on the image(white balanced).This correction increases the difference between darker/lighter regions at a cost of a loss of details in the under/over exposed regions. To compensate for the above loss ,a second input is used which corresponds to the sharpened version of the white balanced image.

So, the unsharp masking principle is used so as to blend a blurred version of the image with the image to sharpen.

The formula which defines the sharpened image is :

$$S = I + \beta(I - G*I)$$

In practice the selection of β is not trivial. A small value depicts that the image is not sharpened while a large value shows over-saturated regions in the image. To rectify this problem normalized unsharp masking is used which is represented as follows.

$S = (I + \mathcal{N}\{I - G * I\})/2,$	Equ – 6 [1]

This second input helps in reducing the degradation caused by scattering.

B. <u>Weights of the Fusion Process</u>

The pixels with high weight values are more represented in the final image. They are thus represented in the form of saliency metrics.

- **Laplacian contrast weight:** In this global contrast is estimated as a result of the Laplacian filter applied to each input luminance channel. It is not much effective as it cannot differentiate between ramp and flat regions.
- **Saliency weight:** It aims to emphasize the objects that lose their prominence in the underwater scene. It is derived from the concept of center-surround contrast. The drawback of using this is it tends to favor highlighted regions.
- **Saturation weight:** It enables the fusion algorithm to adapt to the chromatic information. It can be calculated using the following formula.

$W_{Sat} = \sqrt{1/3\left[(R_k - L_k)^2 + (G_k - L_k)^2 + (B_k - L_k)^2\right]}$	Equ -7 [2]

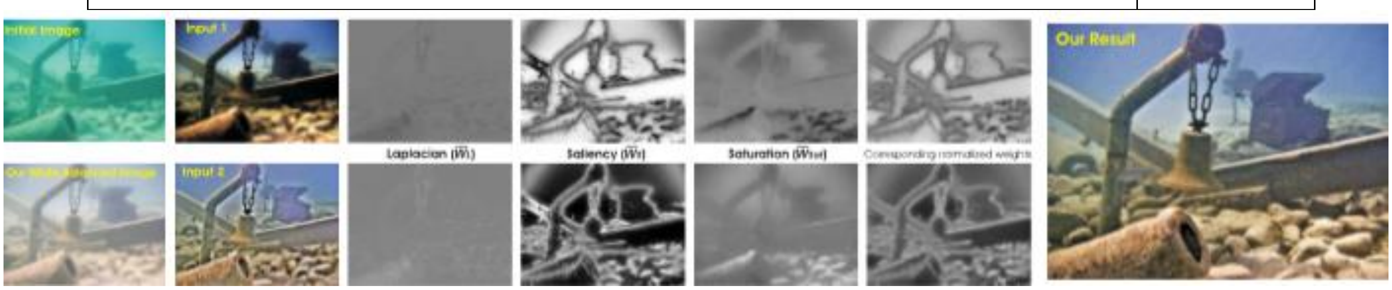

Fig-7

Fig-7 shows the normalized weights of the corresponding weights.

C. Naïve Fusion Process

The reconstructed image is obtained by fusing the defined inputs with the weight measures at every pixel location (x). It is given as follows:

$\mathcal{R}(x) = \sum_{k=1}^{K} \bar{W}_k(x) I_k(x)$	Equ -8 [1]

This approach introduces undesirable halos, So to overcome this problem multi–scalar linear is employed.

D. Multi-Scale Fusion Process

The multi-scale decomposition is based on Laplacian pyramid. The pyramid representation aims to decompose an image into a sum of bandpass images. Each level filters the input image using a low pass Gaussian kernel *G*.

$\begin{aligned} I(x) &= I(x) - G_1\{I(x)\} + G_1\{I(x)\} \triangleq L_1\{I(x)\} + G_1\{I \\ &= L_1\{I(x)\} + G_1\{I(x)\} - G_2\{I(x)\} + G_2\{I(x)\} \\ &= L_1\{I(x)\} + L_2\{I(x)\} + G_2\{I(x)\} \\ &= \ldots \\ &= \sum_{l=1}^{N} L_l\{I(x)\} \end{aligned}$	Equ – 9 [1]

Multi-scale fusion is motivated by the human visual system, which is sensitive to the sharp transitions appearing in smooth image patterns, while being less sensitive to variations on the edges and textures.

It can be approximated as visually pleasant single-scale procedure. This approximation should be taken when complexity is an issue, since it also turns the multi resolution process into a spatially localized procedure.

Chapter 6:

Results and Discussion

1. Underwater white balancing evaluation:

To describe the robustness of the white balancing method , we take a set of pictures by various cameras as shown in table-1. These cameras are set to their widest zoom settings. Many methods are applied and are compared with the proposed white balancing strategy.

	Grey-Edge		Shades of Grey		max-RGB		Grey-World		Ancuti et al.		Our WB	
	CIE2000	Q_u	CIE2000	Q_u	CIE2000	Q_u	CIE2000	Q_u	CIE2000	Q_u	CIE2000	Q_u
Cannon D10	14.8368	0.5810	9.1694	0.6185	12.8245	0.5737	9.9290	0.6435	9.4534	0.6321	9.4055	0.6303
FujiFilm Z33	18.8104	0.5798	9.2788	0.7394	15.4398	0.6384	9.3965	0.7601	10.7183	0.6874	12.7031	0.6599
Olympus T6000	17.4335	0.6092	9.5245	0.6568	14.6394	0.6136	11.7903	0.6966	10.2549	0.6805	8.4598	0.7164
Olympus T8000	18.5834	0.5947	13.5059	0.6844	17.4925	0.6195	14.4812	0.6396	11.7469	0.7023	8.9903	0.7128
Panasonic TS1	12.8787	0.6501	12.9742	0.6672	15.3450	0.6756	13.3113	0.6419	12.9008	0.6814	8.9686	0.6858
Pentax W60	13.1949	0.5573	7.6364	0.6317	9.7164	0.5634	9.8853	0.7009	7.7004	0.6497	8.9194	0.6447
Pentax W80	12.9933	0.6816	8.3278	0.7510	10.7710	0.6816	8.7854	0.6993	8.3631	0.7263	7.2347	0.7652
Average	15.5330	0.6077	10.0596	0.6784	13.7469	0.6237	11.0827	0.6831	10.1625	0.6801	9.2402	0.6879

Table- 1

According to the results, Max RGB and Gray-Edge Methods are not able to remove entirely the color casts, The Gray World and Shades-of-Grey strategy show better results.

2. Underwater Dehazing Evaluation:

The strategy is used for both images as well as the videos. The underwater video dehazing the algorithm has an advantage that is uses less number of parameters. Table-2 provides the associated quantitative evaluation using various metrics.

	He et al.			Ancuti&Ancuti			Drews-Jr			Galdran et al.			Emberton et al.			Ancuti et al.			Our method		
	PCQI	UCIQE	UIQM	PCQI	UCIQE	UIQM	PCQI	UCIQE	UIQM	PCQI	UCIQE	UIQM	PCQI	UCIQE	UIQM	PCQI	UCIQE	UIQM	PCQI	UCIQE	UIQM
Shipwreck	1.012	0.565	0.565	0.998	0.629	0.578	0.649	0.550	0.492	0.920	0.646	0.605	0.945	0.632	0.588	1.131	0.634	0.629	1.172	0.632	0.668
Fish	1.023	0.602	0.509	1.047	0.650	0.532	0.863	0.623	0.571	0.835	0.527	0.528	1.156	0.705	0.759	1.089	0.669	0.598	1.117	0.667	0.624
Reef1	1.000	0.612	0.592	0.963	0.657	0.643	1.046	0.649	0.657	0.794	0.576	0.565	1.078	0.660	0.690	0.978	0.655	0.674	1.083	0.658	0.687
Reef2	0.774	0.702	0.749	0.899	0.683	0.724	0.483	0.659	0.653	0.769	0.633	0.671	0.607	0.718	0.757	0.983	0.718	0.733	1.075	0.711	0.781
Reef3	1.022	0.606	0.578	1.123	0.661	0.667	0.793	0.620	0.584	0.883	0.533	0.524	0.943	0.678	0.677	1.191	0.705	0.737	1.276	0.697	0.766
Galdran1	1.056	0.593	0.578	1.030	0.631	0.601	0.749	0.544	0.519	0.507	0.529	0.569	1.147	0.652	0.664	1.125	0.643	0.669	1.152	0.659	0.680
Galdran9	0.983	0.426	0.421	1.016	0.558	0.481	0.864	0.536	0.410	1.158	0.596	0.648	1.136	0.630	0.577	1.123	0.667	0.622	1.192	0.633	0.663
Ancuti1	0.860	0.485	0.353	1.032	0.561	0.412	0.909	0.499	0.383	0.962	0.641	0.458	1.036	0.499	0.407	1.074	0.588	0.547	1.022	0.594	0.507
Ancuti2	0.649	0.456	0.437	1.077	0.595	0.651	0.475	0.492	0.344	0.591	0.529	0.525	0.603	0.529	0.425	1.015	0.590	0.683	0.914	0.592	0.687
Ancuti3	1.071	0.577	0.596	1.071	0.643	0.616	0.973	0.535	0.492	1.021	0.614	0.646	1.129	0.555	0.563	1.171	0.652	0.693	1.207	0.664	0.651
Average	0.945	0.562	0.538	1.026	0.627	0.590	0.780	0.571	0.511	0.844	0.582	0.574	0.978	0.626	0.611	1.088	0.647	0.659	1.121	0.651	0.671

Table -2

Overall, we conclude that our approach generally results in good perceptual quality, with significant enhancement of the global contrast, the color, and the image structure details.
The major limitations are of the fact that the color cannot always be fully restored and some haze is maintained. The performance of the method is shown in fig -8.

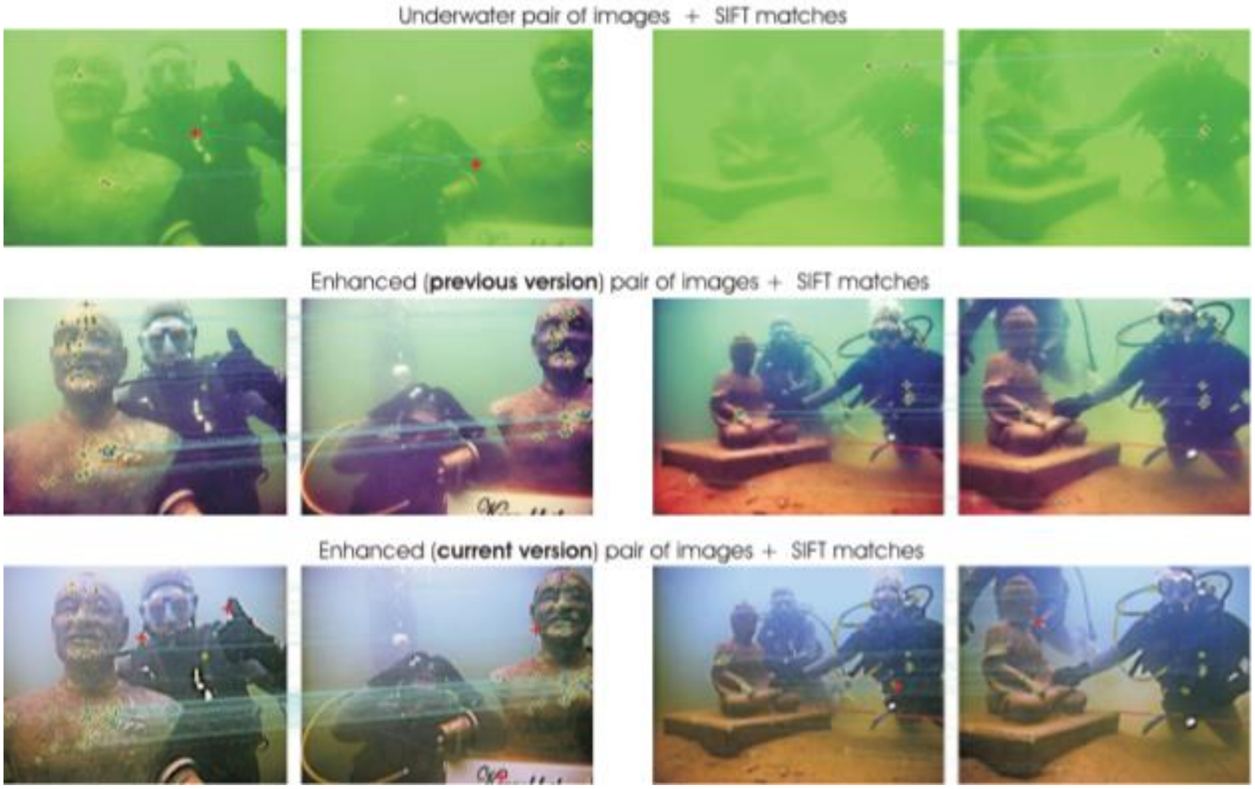

Fig- 8

3. Applications:

- Segmentation aims to divide images into disjoint and homogenous regions with respect to some characteristics.
- Local feature points matching is a fundamental task of many computer vision applications.

Conclusions

The approach discussed is an alternative to enhance underwater videos and images. This strategy builds on the fusion principle and does not require additional information other than the single original image.

As a result our approach is able to enhance a wide range of underwater images to a great extent. It recovers important faded features and edges.

Moreover, the method demonstrates the utility and the relevance of the proposed image enhancement technique which uses the concept of white balance and multi-scale fusion for several challenging underwater computer vision applications.

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