Investigations on Colour Correction Techniques of Underwater Images

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***Abstract*—As light propagating through water affected by serious consequences of scattering and attenuation, underwater vision may get distorted and makes quality of underwater image poor. There are different techniques exist for the colour correction of degraded underwater images. Some of these techniques overlook the reliance of wavelength on the attenuation or presupposing a definite spectral outline. Recent developments in the area of correction and enhancement are investigated in detail. At first, a method based on single image prior dark channel prior is taken for study. Along with this method, colour enhanced versions of underwater images are simulated using colour balance and fusion, HSV colour space and histogram equalization method and finally using local colour mapping with colour transfer. A comparison based on parameters entropy and mean is used. An enhanced image would have higher values of these parameters is the assumption made. A user study is also included as a complementary method for comparison of different method for colour enhancement of underwater images.**

***Index Terms*—Underwater, local colour mapping, colour transfer**

I. INTRODUCTION

Many rare attractions including aquatic animals and fishes, astonishing landscape, and strange shipwrecks [1] are present in underwater environment. Underwater imaging is an important source of interest in various sections of research and technology. These applications include checking up of cables and infrastructures in water, observation of artificial articles, managing of autonomous underwater vehicles, aquatic life research. Generally, underwater images suffer from degeneration, including small values for contrast, colour shed, and disturbances. Degenerations arise because of absorption of light depending on wavelength as well as light scattering and also by the consequences of imaging devices with less precision [2]. Light scattering as well as absorption cause attenuated light transmission. Moreover, they introduce a scattered version of surrounding light. The intensity of the scene becomes weaker due to attenuated direct transmission and introduces colour casts. The surrounding light which is a scattered version results the loss of appearance of the visual. Numerous complex elements such as temperature of water and amount of salinity as well as the category and amount of particulates present in water influences the magnitude of attenuation and scattering [2]. Recovery of appearance and colour of underwater images becomes much more difficult for serious degeneration. For underwater vision tasks and research, colour is extremely relevant. Therefore, how to obtain the actual colour of underwater images effectively is becoming a difficult task.

II. LITERATURE SURVEY

This section presents an overview of earlier approaches used to enhance colour and visual quality of underwater images.

A. Propagation of Light in Underwater

The availability of light in water relies on several factors [1]. As the time of day, has an impact in light incidence angle which causes interactivity between sunlight and sea surface. Structure of air and water interface also determines light availability. Because of position specific colour cast, diving location also influences on availability of light. Green and blue casts are actuated by deeper oceans, whereas, cyan colour is actuated by tropical waters.

Particle density in water becomes several times that of air and light has to pass through these particles. As a result, subsea water take in several light wavelengths. Due to the refractive index of water, underwater images appear 25% larger than its actual size [2].

B. Related Works

The primary work on colour transfer is the work by Reinhard et al. [3] which was a straightforward and effective approach that matches the means and the standard deviations of the global colour distributions of the two images in the LAB color space. Contemporary developments based on generative models, especially Generative Adversarial Networks (GANs) are very effective in correcting underwater images as the results look like normal air images [4]. The difficulty arising in such models is that the necessity of large-scale computational resources for the training process.

III. SYSTEM DESCRIPTION

This section consists of four approaches that can be used to enhance colour and visual quality of underwater images.

A. Haze Removal Using Dark Channel Prior

1) Estimating the Transmission: Haze image model is given by:

$$I(x) = J(x)t(x) + A(1 - t(x)) \quad (1)$$

We assume that the atmospheric light A is already given [5]. An automatic technique to estimate A is proposed.
First normalized haze imaging equation (1) by

$$I^c(x)/A_c = t(x)(J^c(x)/A_c) + 1 - t(x) \quad (2)$$

We normalize each colour channel independently. Then we suppose that $\tilde{t}(x)$, the transmission in a local patch is constant. We denote this transmission as $\tilde{t}(x)$.

Then, we calculate the dark channel on both sides of (2). Equivalently, we put the minimum operators on both sides. Transmission $\tilde{t}$ is given by:

$$\tilde{t} = 1 - \min_{y s\Omega(x)} (min_c \frac{I^c(y)}{A^c}) \quad (3)$$

2) Soft Matting: We find that the haze image model (1) has a alike form as the image matting equation

$$I = F\alpha + B(1 - \alpha), \quad (4)$$

F and B represent foreground and background colours respectively, and is the foreground opacity. In haze image model (1), a transmission map is absolutely an alpha map. Therefore, to extract the transmission we can apply a closed-form framework of matting.

Indicate the extracted transmission map by t(x). Rewriting t(x) and $\tilde{t}(x)$ in their vector forms as t and $\tilde{t}$, cost function is minimized as follows:

$$E(t) = t^T Lt + \lambda(t - \tilde{t})^T(t - \tilde{t}) \quad (5)$$

A smoothness term is used as the first term and a data term with a weight λ is used as the second term.
The solution of sparse linear system in (6) gives optimal t

$$(L + \lambda U)t = \lambda\tilde{t} \quad (6)$$

Where U is an identity matrix of the same size as L. We set a small λ.

3) Estimating the Atmospheric Light: We made an assumption that atmospheric light A is already available. In this section, we propose a method to estimate A [5]. In the previous works, the color of the most haze-opaque region is used as A or as A's initial guess. But, the detection of the most haze-opaque region was done with less supervision. An assumption made was the most haze-opaque region was the pixels with higher brightness in the hazy image. This is true only when the weather is overcast and the sunlight can be ignored. In this case, the atmospheric light is the only illumination source of the scene.

4) Recovering the Scene Radiance : With the atmospheric light and the transmission map, by (1) scene radiance can be retrieved. When the transmission t(x) is close to zero the proximity of direct attenuation term J(x)t(x) to zero is high. The scene radiance, J which is directly retrieved is vulnerable to noise. Therefore, we restrict the transmission t(x) by a lower bound t_0, i.e., a little quantity of haze maintained in haze regions [5] higher density of haze. The final scene radiance J(x) is retrieved by (7),

$$J(x) = \frac{I(x) - A}{max(t(x), t_0)} + A \quad (7)$$

A typical value of t_0 is 0.1. As scene radiance is generally not bright as atmospheric light, after haze removal image looks dim. Therefore, for better display exposure of J(x) increased.

B. Underwater Image Enhancement Using Multi-Scale Fusion

The method is given by the following figure.

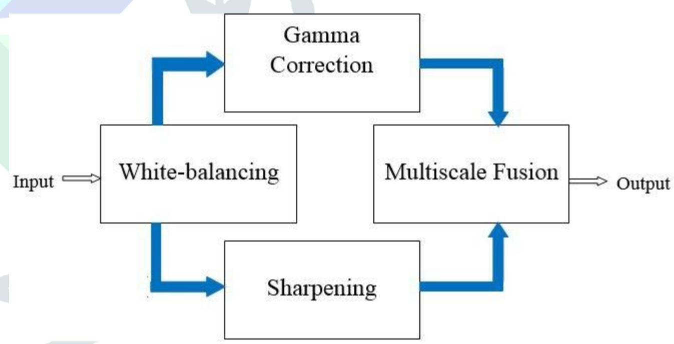

Fig. 1. Framework of Multi-Scale Fusion Method

The approach builds on the fusion of multiple inputs, but derives the two inputs to combine by correcting the contrast and by sharpening a white-balanced version of a single native input image [1]. The white balancing stage aims at removing the color cast induced by underwater light scattering, so as to produce a natural appearance of the sub-sea images. The multi-scale implementation of the fusion process results in an artifact-free blending.

1) Colour Balance: For every pixel location compensated red channel I_{rc} is given by

$$I_{rc}(x) = I_r(x) + \alpha.(\bar{I}_g - \bar{I}_r).(1 - I_r(x)).I_g(x), \quad (8)$$

In some cases where the blue channel faces large attenuation red channel compensation becomes insufficient to compensate colour casts. Therefore, compensation for blue channel I_{bc} is calculated by

$$I_{bc}(x) = I_b(x) + \alpha.(\bar{I}_g - \bar{I}_b).(1 - I_b(x)).I_g(x), \quad (9)$$

2) Multi-Scale Fusion: In fusion process, the image is reconstructed by fusing the inputs from gamma correction and sharpening with weights at each pixel position.

$$R_l(x) = \sum_{k=1} tt_l \cdot \bar{W}_k(x) \sum_{k=1} L_l\{I_k(x)\} \quad (10)$$

L_l and tt_l respectively. Each input I is disintegrated to Laplacian pyramid [1]. $\tilde{W}(k)$ is normalized weight map. $\tilde{W}(k)$ is disintegrated by utilizing Gaussian pyramid.

C. HSV and Histogram Equalization for Underwater Colour Correction

The framework of the proposed method is shown in the

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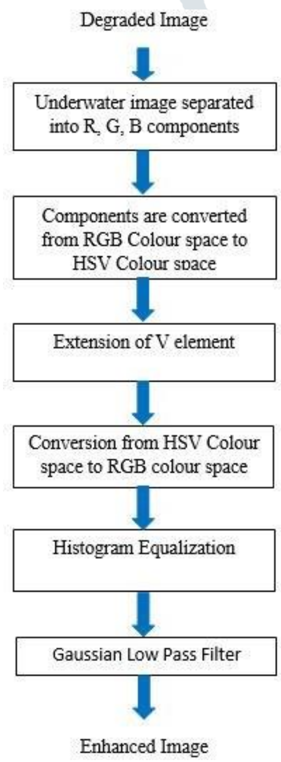

Fig. 2. Framework of HSV and Histogram Equalization Method

As depicted in the above framework, the degraded underwater image is separated out into corresponding red, green and blue colour components [6]. Then R,G,B colour components are converted into HSV colour space. After that the V-element is extended, and is done at the start and end of the prescribed interval. Then the H,S,V elements are converted back to R,G,B components. For enhancing image histogram equalization is performed on R,G,B colour constituents. For achieving better results, gaussian filtering is also applied.

D. Underwater Image Enhancement Using Colour Mapping and Colour Transfer

Earlier works related to underwater image enhancement were depending on either local colour mapping or global colour transfer. But, in this novel approach improvement in image is achieved by combining both of these approaches that result in a powerful strategy [7]. This model is based on an affine model given by $y = Ax+b$ which maps an input pixel to output pixel. Here global colour transfer is obtained by transfer of global information pre-decided reference images that have required global colour distribution. A new regularizer which is capable of matching covariances of output transformed image and the reference image through an affine transform.

The proposed regularizer is given as:

$$\min_{A,b}(f(A,b)) \stackrel{def}{=} \| AX - Y + b1_3^T \|_F^2 + \frac{\lambda_1}{2} \| AC_iA^T - C_r \|_F^2 + \frac{\lambda_2}{2} \cdot \| A \|_F^2 + \| b \|_2^2 \quad (11)$$

1) Local Colour Mapping: The local color mapping term in this model $\| AX - Y + b1_3^T \|_F^2$ correlates the N selected pixels. Here N is the number of columns in X and Y.

2) Global Colour Transfer: A new regularizer $\| AC_iA^T - C_r \|$ is proposed that correlates colour covariance of input image Ci and colour covariance of image that is taken as reference Cr.

IV. RESULTS, COMPARISON, AND DISCUSSION

Enhancement in colour and visual quality of degraded images are obtained are included in this section. Along with this a brief comparison of performance of each method is also included. All the simulations were done using MATLAB.

A. Results

1) Simulated Results of Dark Channel Prior:

Fig. 3. Results for Dark Channel Prior method

2) Simulated Results of Multi-Scale Fusion:

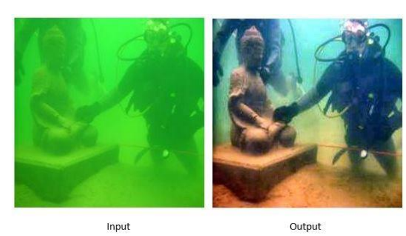

Fig. 4. Results of Multi-Scale Fusion Method

3) Simulated Results of HSV and Histogram Equalization:

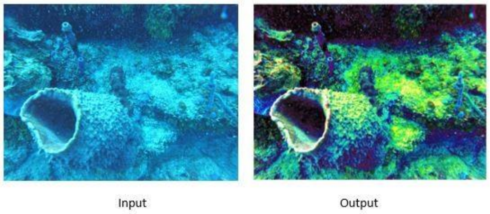

Fig. 5. Results of HSV and Histogram Equalization Method

4) Simulated Results of Colour Mapping and Colour Transfer :

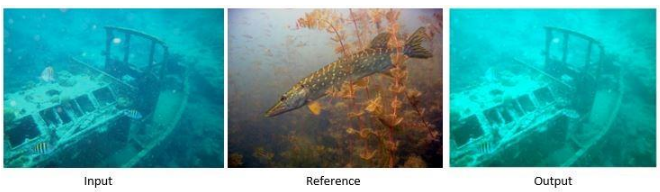

Fig. 6. Results of Colour Mapping and Colour Transfer Method

B. Comparison and Discussion

In order to evaluate effectiveness of different methods for colour enhancement, entropy and mean value were used [6]. The information contained in an image is represented by entropy. Therefore, a rise in the value of entropy indicates increase in visual quality of the image. Mean value represents the mean value of colours in an image. It is the measure of improvement in an image. The mean value of an enhanced image will be higher than the original image.

TABLE I
COMPARISON WITH RESPECT TO ENTROPY AND MEAN VALUE

Method	Entropy(Input)	Entropy(Output)	Mean(Input)	Mean(Output)
DCP	0.0302	0.204	13.7123	12.8681
Multi-Scale Fusion	0.0921	0.3143	13.5554	14.1824
HSV and HE	0.0728	0.9043	8.3773	10.8178
Colour Mapping and Transfer	1.4943	1.961	8.1258	12.5124

From table I, it is clear that the entropy value of enhanced image for each method is higher than that of degraded input image. So, we can infer that the enhanced image containsmore information than degraded images. Among all four methods, HSV and histogram equalization method has the higher rise in entropy for enhanced images than other methods. Dark channel prior method has least rise in entropy. So with respect entropy HSV and histogram equalization method has higher performance than other methods.

On comparing with mean value, all methods except dark channel method shows increase in mean value for enhanced image than the original degraded image. For dark channel method, the original image has higher mean value than processed image. Colour mapping and colour transfer method has higher increase in mean value than the other three methods. Therefore, colour transfer and mapping has improved effectiveness than other methods

In a user study, 5 participants who are familiar with image processing was chosen to give scores for the results of each method [2]. Range of scores was from 1 to 8 were 1 indicate a worst result and 8 indicate a best result. The degraded input was given a score 3 as reference value. Average of scores given by all 5 participants was taken to evaluate effectiveness in enhancement in colour and visual quality of each method. Participants were unaware about which method each enhanced image belongs to. A good result with the highest score will have abundant information, larger values of contrast and visibility, whereas a bad result with lower scores will have noise, regions with lower visibility.

TABLE II
COMPARISON WITH RESPECT TO USER STUDY

Method	P1	P2	P3	P4	P5	Average
DCP	5	5	6	5	6	5.4
Multi-Scale Fusion	7	7	8	8	8	7.6
HSV and HE	8	7	8	8	7	7.6
Colour Mapping and Transfer	5	6	6	6	5	5.6

From user study given in table I, it is clear that the effectiveness in colour correction and enhancement is higher for methods, multi-scale fusion and HSV and histogram method than the other two methods. Both these methods give the same score. Dark channel prior method was awarded the last score.

V. CONCLUSION

In this work, we investigated a few methods for colour correction and visual quality enhancement of degraded underwater images. From the methods investigated two methods were founded as most useful in the enhancement of underwater images. Two other methods were also able to enhance but, there was still notable degradation in processed images. Comparison for obtaining effectiveness was done in two methods. One method was based on entropy and mean value and the other was a user study. In evaluating both the comparison strategy, multi-scale fusion and HSV and histogram equalization methods were found most useful in enhancing degenerated underwater images. As future scope, new methods based on adversarial methods which are most useful can be developed for underwater colour correction.

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