CS517 Project

Implementation Of Underwater Image Enhancement

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1. List of abbreviations

RGB	Red, Green, Blue
PSNR	Peak Signal to Noise Ratio
MSE	Mean Squared Error
HSV	Hue, Saturation, Value
PCA	Principal Component Analysis

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4. Abstract

Underwater images find application in various fields, like marine research, inspection of aquatic habitat, underwater surveillance, identification of minerals, and more. However, underwater shots are affected a lot during the acquisition process due to the absorption and scattering of light. As depth increases, longer wavelengths get absorbed by water; therefore, the images appear predominantly bluish-green, and red gets absorbed due to higher wavelength. These phenomenons result in significant degradation of images due to which images have low contrast, color distortion, and low visibility. Hence, underwater images need enhancement to improve the quality of images to be used for various applications while preserving the valuable information contained in them.

5. Dataset Used

We have selected seven images for our project from [1]. The following figure shows the images and their corresponding reference images provided in the dataset.

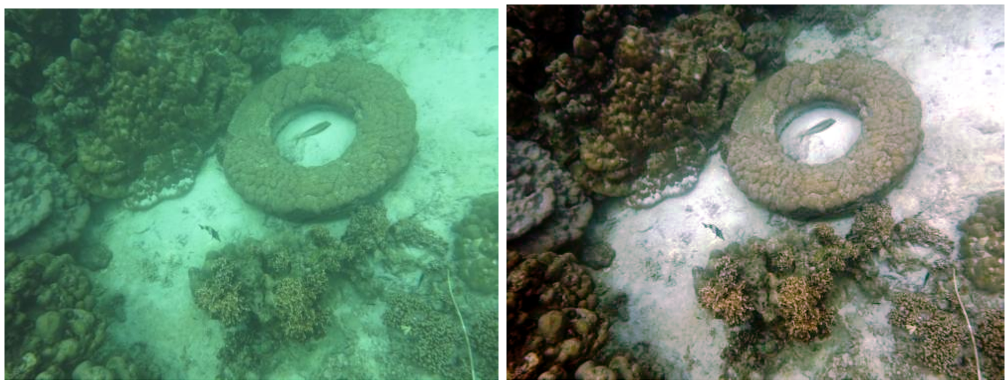


Fig 5.1 Images (left) and their corresponding Reference Images(right)

6. Approach

We have followed the following steps in order to enhance the underwater images:

1. As evident from the images shown in Fig 5.1(left), most of the images have a bluish and greenish appearance. So, we plotted a histogram of RGB channels for our image.
2. From the histogram, we observed that in all the images, the red channel is concentrated on the left side of the histogram as the red color gets absorbed due to a higher wavelength.
3. Fig 6.1 a) shows the histogram of images with a greenish appearance(image 1) and 6.1 b) shows the histogram of images with a bluish appearance(image 3). It was also observed that for images with a greenish appearance, the histogram of the B channel is also concentrated towards the left.
4. In addition to the histogram, we also observed the true R, G, and B components of all images in order to display the degradation of each channel. It can be seen from Fig 6.2 a) and Fig 6.2 b) that the Green channel is least degraded as compared to the Red and Blue channel.
5. So, the first step in enhancing the underwater images is color correction.

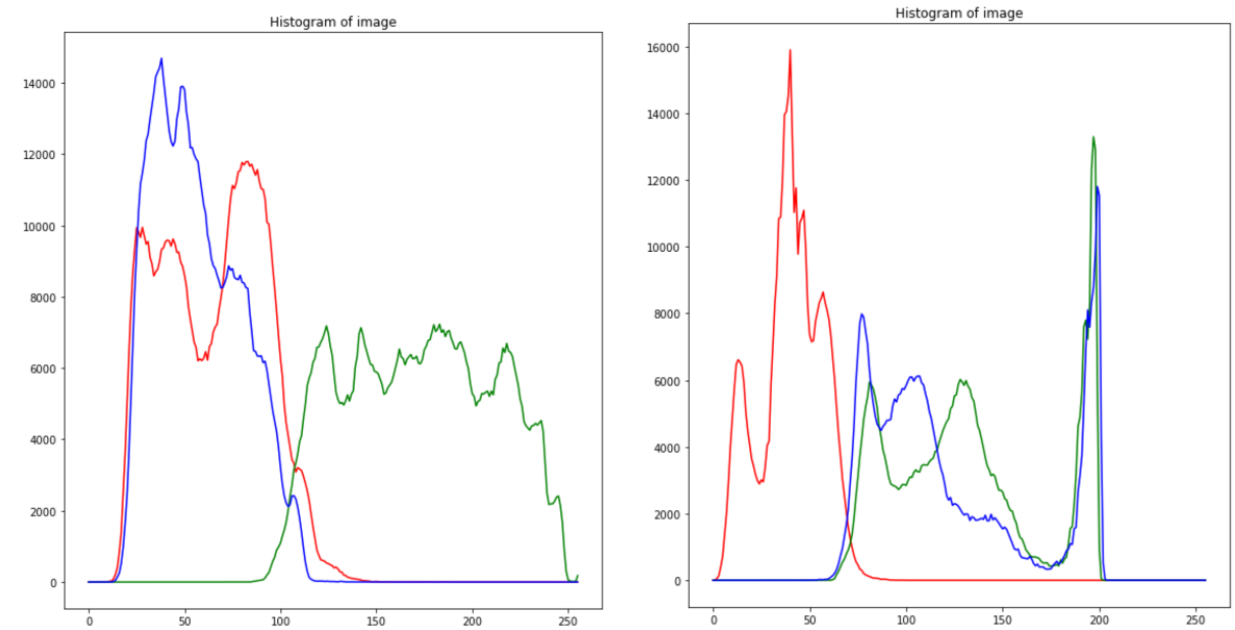


Fig 6.1 a) Histogram of image 1 b) Histogram of image 3

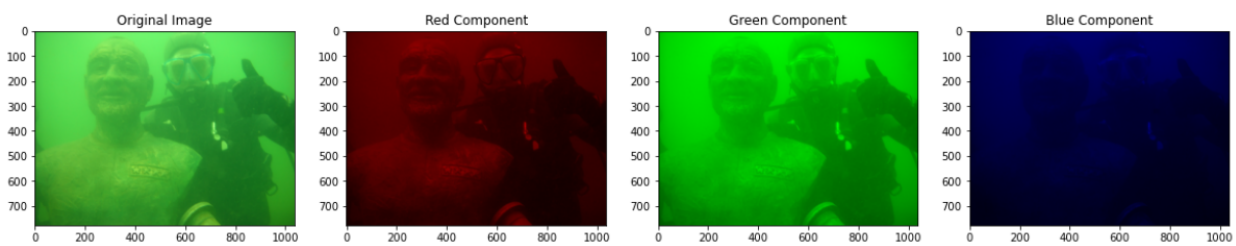


Fig 6.2 a) RGB components of image 1

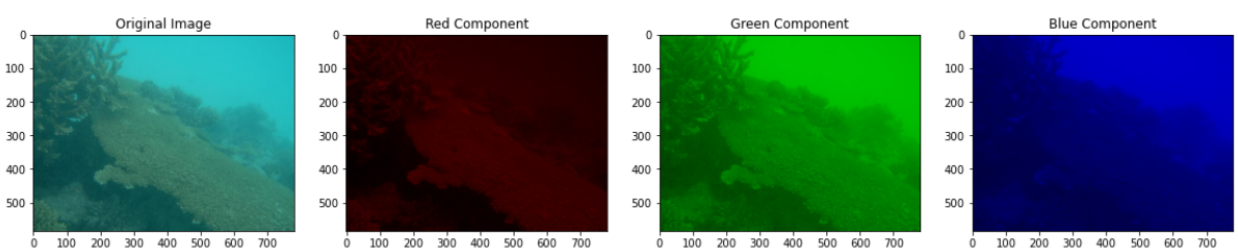


Fig 6.2 b) RGB components of image 3

6. For color correction, first, we need to compensate for the degradation of the R channel and in cases where images have a greenish appearance B channel also needs to be compensated. The compensation process is to add a fraction of the green channel to the Red and Blue(when required) channel as it is the least degraded channel.

   The formula for the compensated red channel I_{rc} at every pixel location (x)

   $$I_{rc}(x) = I_r(x) + (\bar{I}g - \bar{I}r) * (1 - I_r(x)) * I_g(x)$$

   The formula for the compensated blue channel I_{bc} at every pixel location (x)

   $$I_{bc}(x) = I_b(x) + (\bar{I}g - \bar{I}b) * (1 - I_b(x)) * I_g(x)$$

   Ir, Ig represent the red and green color channels of the image I, $\bar{I}r$, $\bar{I}g$, $\bar{I}b$ denote the mean value of I_r, I_g, and I_b respectively. [2]

7. After performing the compensation, the next step in color correction is to perform white balancing using the Gray World algorithm.
8. The color-corrected image is observed to have low color distortion but it still has low contrast, and edges are also not clearly visible.
9. So, the next step is to enhance the contrast of the color-corrected image using Global Histogram Equalization.
   9.1. The Equalization is performed by first converting the image to the HSV domain and then equalizing the *Value* component. The contrast-enhanced image is then obtained by concatenating the original Hue component, original Saturation component, and equalized Value component[3].

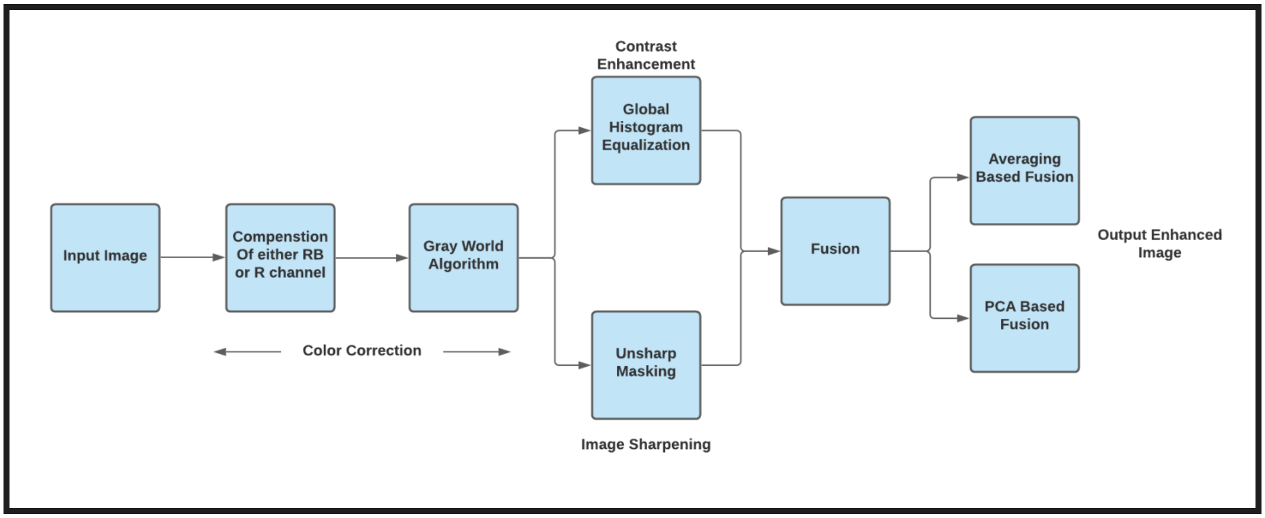


Fig 6.3 Block diagram of the Process

10. Next, we perform unsharp masking to sharpen the color-corrected image.

$g_{MASK}(x, y) = f(x, y) - Gaussian\_Blur(f(x, y))$

$g(x, y) = f(x, y) + g_{MASK}(x, y)$

$g(x, y) = 2*f(x, y) - Gaussian\_Blur(f(x, y))$

Here, f(x, y) is the image on which we want to perform unsharp masking

11. At this stage, we have a contrast-enhanced image and sharpened image, now we need to perform fusion to integrate these two images and get a final enhanced image.
12. There are two techniques that we have used for the fusion of two images.

12.1. Averaging-based Fusion

In this method, the resultant fused image is obtained by taking the average intensity of corresponding pixels from both the input image.

$$F(i,j) = \frac{A(i,j) + B(i,j)}{2}$$

A(i,j), B(i,j) are input images and F(i,j) is fused image.

12.2. PCA-based Fusion

For PCA based fusion, the following steps are followed for each channel of the image

- First, the components for both images are flattened to make a column vector.
- Then, a 2*N (N=x*y, x, y is the size of the image) matrix is created by concatenating the two column vectors obtained above.
- Next, find the mean of each column and subtract it from the respective column
- Now, find the covariance matrix of the matrix obtained above after subtracting the mean.
- Find the eigenvalues and eigenvectors for the covariance matrix.
- The coefficient are obtained as follows:
    - Select the eigen vector corresponding to the highest eigen value, it will be a column vector of dimension 1*2
    - Coefficient1 = $\frac{V[0]}{V[0]+V[1]}$
    - Coefficient2 = $\frac{V[1]}{V[0]+V[1]}$

After obtaining the coefficient for both the images for each channel, a fused image is obtained by multiplying the coefficient of the respective channel to their respective images for each pixel value.[4]

13. After the fusion process, the final image obtained is an enhanced image.

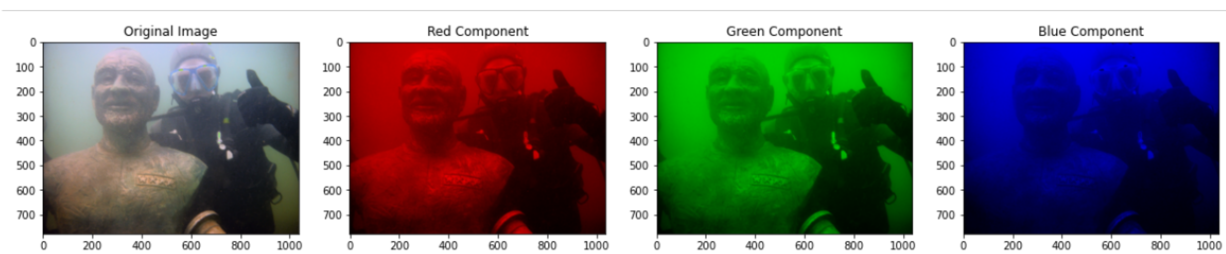


Fig 6.4 a) RGB Components of enhanced image 1

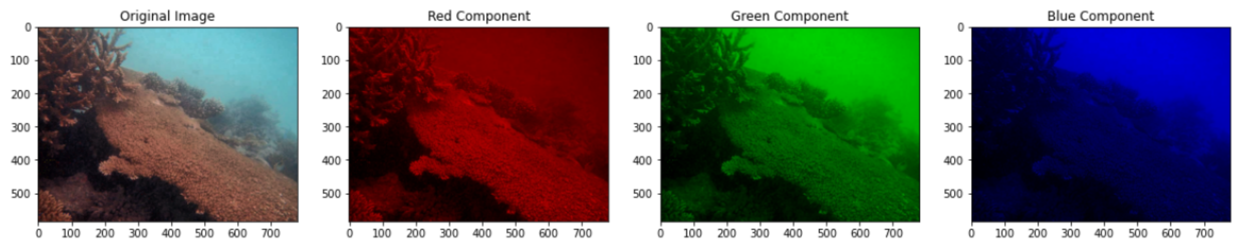
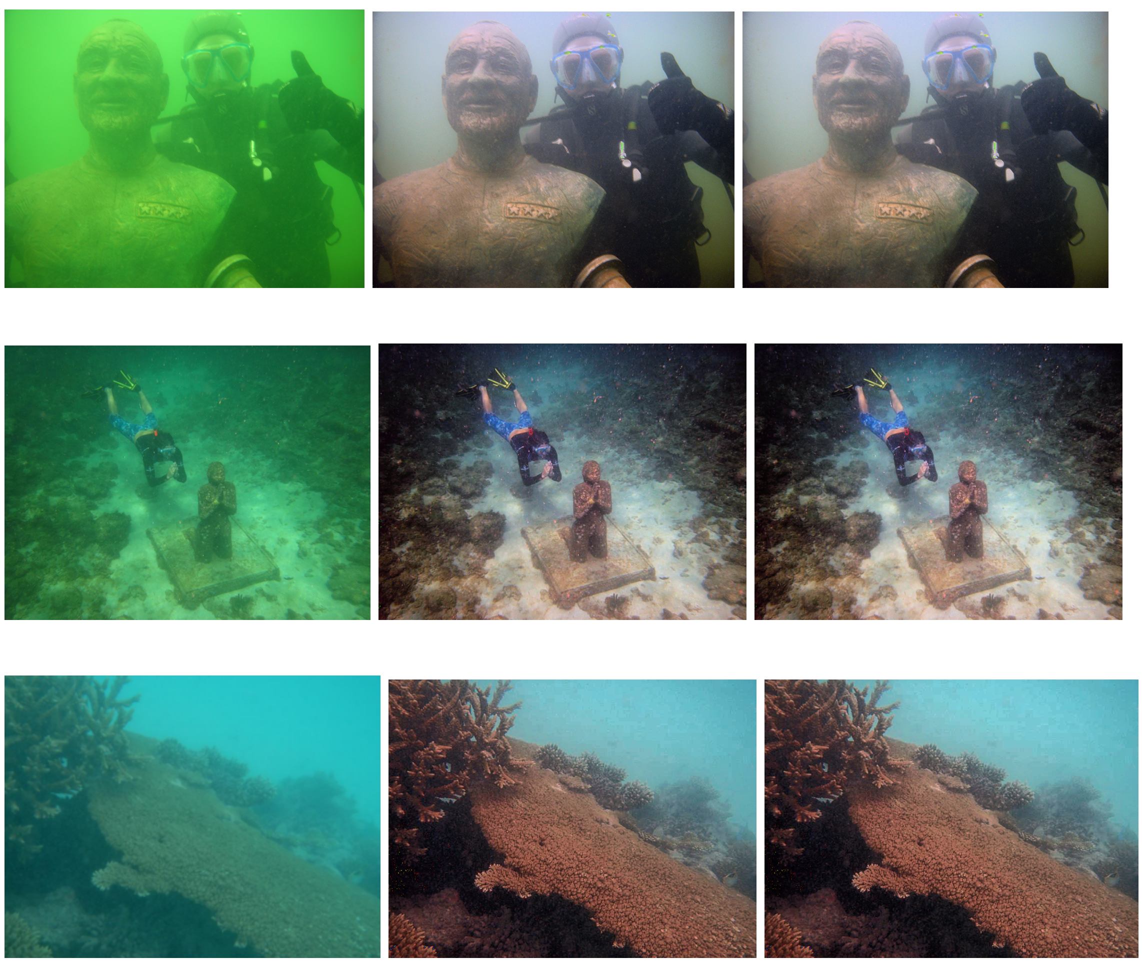


Fig 6.4 b) RGB Components of enhanced image 3

14. Next, we used MSE and PSNR to compare the quality of the images obtained from the above method and the reference image provided in the dataset.

7. Observations & Results



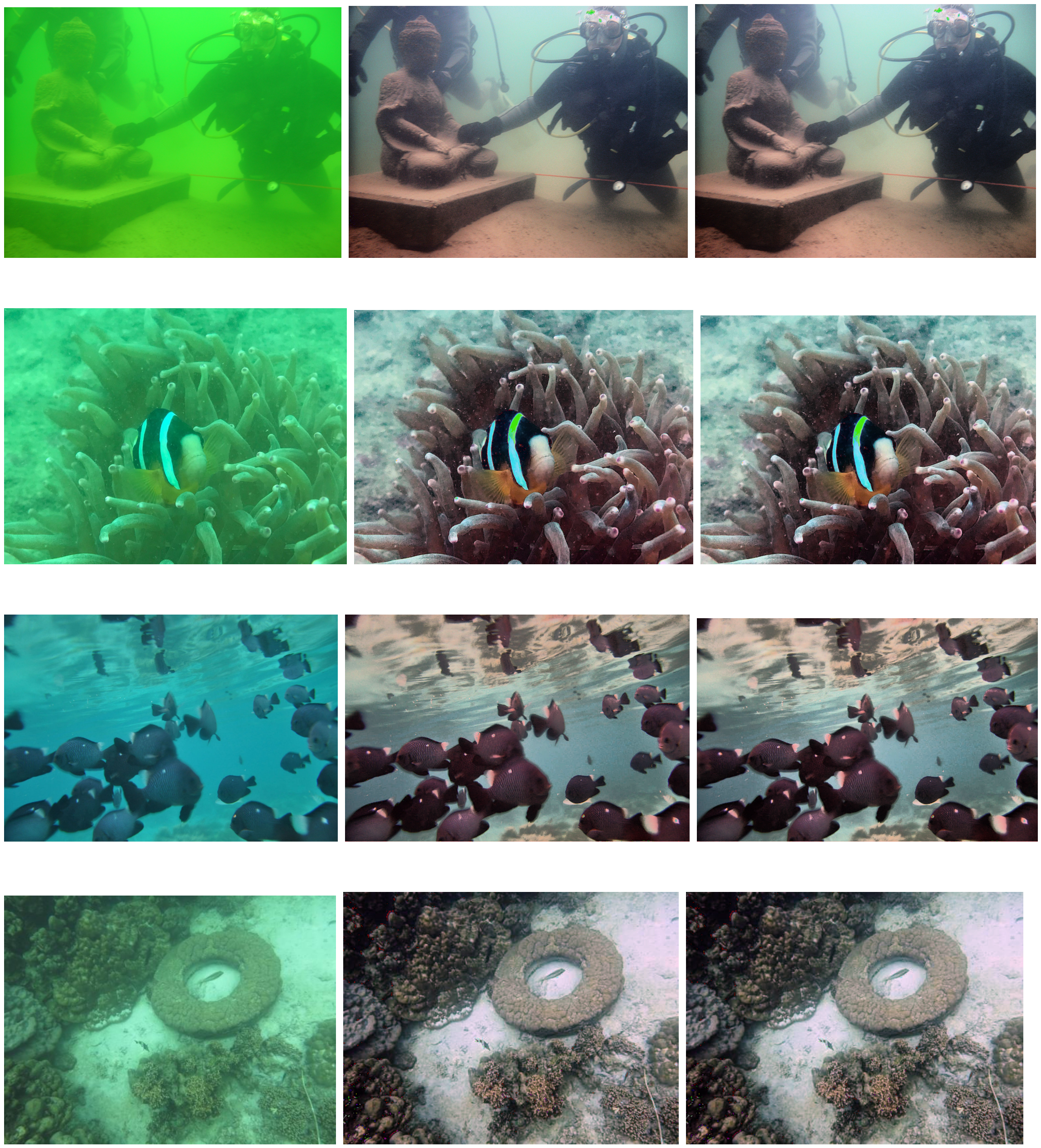


Fig 7.1(left to right) Original Image, Averaging based Fusion Enhanced Image, PCA Based fusion Enhanced Image

By seeing Fig 7.1, we can conclude that the image obtained after the fusion process have better contrast and visibility, and the R, G, B, components are less degraded as shown in Fig 6.4 a) and Fig 6.4 b)

The following table Table 7.1 and Table 7.2 show the MSE and PSNR values of both the averaging-based fusion method and PCA-based fusion method.

Sr. No	Averaging based Fusion			
	Reference Image & Original Image		Reference Image & Our result	
	MSE	PSNR	MSE	PSNR
1	307.7587848574467	23.248699023168	255.3803710029	24.0589284731
2	301.2079594930013	23.342139168511	282.0235875447	23.6279492803
3	330.55965811965	22.9383051019	298.34620644	23.383598408
4	314.2733835242555	23.157727596086	288.2103903637	23.5337072722
5	321.1966878858025	23.063093025935	269.4710988940	23.8256816746
6	320.0508887043189	23.078613234031	322.2196137873	23.0492838809
7	324.693584	23.01606653889	161.9284266666	26.0375726467

Table 7.1 MSE & PSNR for Averaging based fusion method

Sr. No	PCA based Fusion			
	Reference Image & Original Image		Reference Image & Our result	
	MSE	PSNR	MSE	PSNR
1	307.7587848574467	23.2486990231683	260.463545475	260.463545475
2	301.2079594930013	23.3421391685114	272.826347351	23.7719405222
3	330.5596581196581	22.9383051019592	301.161023449	23.3428159651
4	314.2733835242555	23.1577275960860	284.919585862	23.5835805645
5	321.1966878858025	23.0630930259357	265.895315715	23.8836967444
6	320.0508887043189	23.0786132340313	323.386128529	23.0335897372
7	324.693584	23.0160665388935	156.233872	26.1930516469

Table 7.2 MSE & PSNR for PCA based fusion method

Upon seeing the MSE and PSNR values, we can say that images obtained after fusion have low MSE when compared with the MSE of the original image and reference image(except for image 6). And also, the resulting images have higher PSNR as compared to the PSNR of the original image and reference image(except for image 6).

8. Conclusion

With the above method, we were successfully able to enhance the underwater images. We also measured the quality of images obtained from the method using metrics namely, MSE and PSNR. The method used above has a downfall that sometimes it produces blue artifacts on whitish parts of images, particularly in the underwater images when water bubbles are there. So, it's not robust for all types of images. Also, if the image is noisy then firstly image noise should be removed by applying Gaussian smoothing. Then our algorithm can be applied as shown in Fig 6.3.

9. Future Work

9.1. Now the enhancement process is not automated, we have to decide what type of compensation we need like we have to provide a variable flag in the algorithm which takes values 0 and 1, where 0 represents that it is a greenish image and we need to compensate R and B channels while 1 represents that it is a bluish image and we need to compensate only R channel as B is not much degraded. To automate this process, we can employ a deep learning-based model but it would require a large dataset to provide efficient results.

9.2. Improve the robustness of the whole process which could eliminate the downfall mentioned above that it produces bluish artifacts. So, that it works for all possible images.

10. Folder Description

10.1. The raw images which are the input images to our program are in the dataset/raw folder.

10.2. The corresponding reference images are in the dataset/reference folder.

10.3. After running the program, the resulting images are stored in the dataset/results folder.

11. Bibliography

[1] https://li-chongyi.github.io/proj_benchmark.html

[2] C. O. Ancuti, C. Ancuti, C. De Vleeschouwer and P. Bekaert, "Color Balance and Fusion for Underwater Image Enhancement," in *IEEE Transactions on Image Processing*, vol. 27, no. 1, pp. 379-393, Jan. 2018, doi: 10.1109/TIP.2017.2759252.

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[7] L. Bai, W. Zhang, X. Pan and C. Zhao, "Underwater Image Enhancement Based on Global and Local Equalization of Histogram and Dual-Image Multi-Scale Fusion," in IEEE Access, vol. 8, pp. 128973-128990, 2020, doi: 10.1109/ACCESS.2020.3009161.