UNDERWATER COLOR CORRECTION AND IMAGE RESTORATION

Interview Task for Technical Sufficiency

Bedirhan Ziran ELBAN

OUTLINE

FIGURE LIST

1. Reasoning of Unsatisfying Underwater Image Quality

Underwater pictures have been widely employed in marine energy development, marine environment protection, marine military, and other sectors in recent years [1]. When light travels through water, the aqueous medium and water particles absorb and disperse light, as seen in Figure 1.

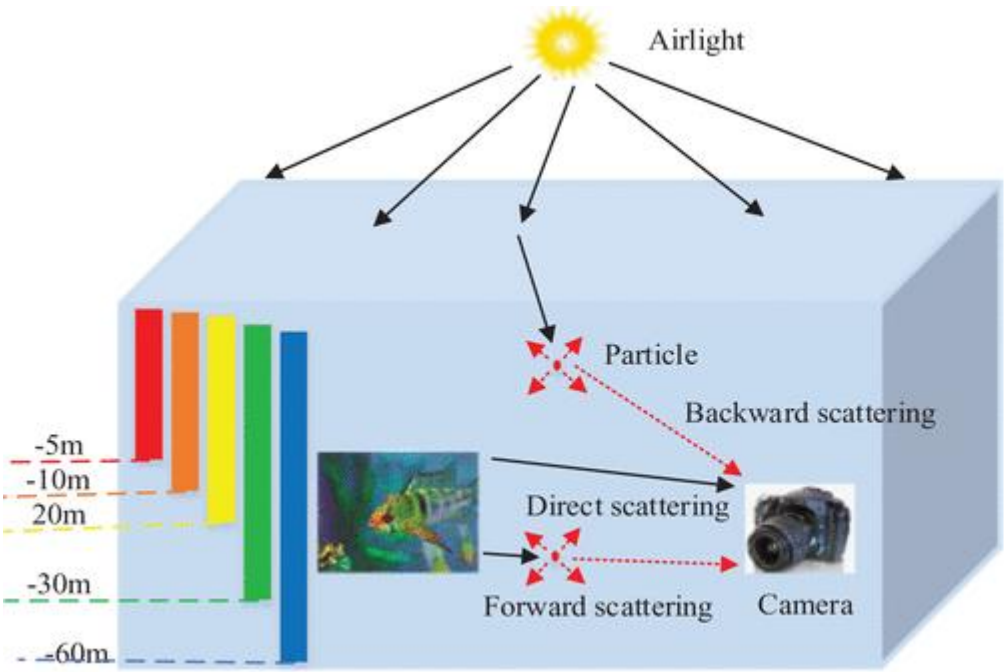

Figure 1: Underwater Light Propagation

The absorption effect creates color distortion in underwater pictures, whereas the scattering effect causes poor contrast and blur [2]. As a result, underwater pictures include flaws including color variation, low contrast, and fuzzy features.

Such damaged pictures have a significant influence on feature extraction and object recognition. As a result, the quality of underwater pictures has evolved into a study focus. Image restoration techniques (IRMs) and image enhancement methods (IEMs) are two known approaches for improving the visibility of underwater pictures (IEMs) [3].

2. Solutions to Improve Image Quality

2.1. Theoretical Background

From the point of image processing view, dehazing algorithms are separated into three main concepts that are Image Enhancement, Image Fusion, and Image Restoration. A brief explanation of these concepts is listed below.

Image Enhancement is the procedure of improving the quality and information content of original data before processing. Common practices include contrast enhancement, spatial filtering, density slicing, and Fuzzy Contrast Correction (FCC). Contrast enhancement or stretching is performed by linear transformation expanding the original range of gray level. Spatial filtering improves the naturally occurring linear features like fault, shear zones, and lineaments. Density slicing converts the continuous gray tone range into a series of density intervals marked by a separate color or symbol to represent different features. FCC is commonly used in remote sensing compared to true colors because of the absence of a pure blue color band because further scattering is dominant in the blue wavelength.

Image fusion encloses all data analysis strategies aiming at combining the information of several images obtained with the same platform or by different spectroscopic platforms. Image fusion can imply building a single multiset or multiway structure with all images involved or connecting the related individual images through regression models. In any case, data analysis performed on structures of fused images always overcomes the results coming from individual image analysis.

Image restoration is the process of recovering an image from a degraded version—usually a blurred and noisy image. Image restoration is a fundamental problem in image processing, and it also provides a testbed for more general inverse problems. Key issues that must be addressed are the quality of the restored image, the computational efficiency of the algorithm, and the estimation of necessary parameters such as the point-spread function (PSF). Basic image restoration techniques are surveyed to provide insight into the nature of the problem. These techniques also provide solutions that are effective in deblurring blurry images with reasonable computational complexity.

2.2. Classifications of Approaches

NETWORK BASED METHODS	**DETAILS**
CNN	CNNs are a type of network that consists of several layers, each with an input, output, and other intermediary levels that transmit their complicated findings to the next linked layers. This effectively decreases the process's computing time.

GAN	To produce a paired dataset, GAN is trained to translate a picture from any arbitrary domain X to another arbitrary domain Y. If X and Y are considered to represent a set of undistorted and distorted underwater pictures, respectively, an image that seems to be underwater while maintaining ground truth may be produced using GAN-derived paired datasets.

SOFTWARE BASED METHODS	**DETAILS**
RESTORATION FILTERS	The primary objective of restoration procedures is to enhance an image in some way. Although there are some overlaps, image enhancement is mostly a subjective process, whereas restoration is primarily an objective procedure.
COLOR CORRECTION	Image restoration endeavors to restore a damaged image by employing a model of the degradation as well as the original image creation; it is basically an inverse issue. These approaches are rigorous, but they need many model parameters (such as attenuation and diffusion coefficients that describe water turbidity) that are only available in tables and can be very variable. Another critical element that must be considered is the depth estimation of a specific item in the image.
FUSION	The fusion process is based on the fusion of information from a collection of images of the target, which may include degraded, color corrected and contrast-enhanced versions of the images.
DARK CHANNEL PRIOR	Besides the sky region, DCP is based on the property of "dark pixels," which have a very low intensity in at least one-color channel. Because of its efficacy in dehazing, the DCP has been used in the bulk of contemporary dehazing approaches. The four key phases of DCP-based dehazing approaches are atmospheric light estimate, transmission map

	estimation, transmission map refining, and picture reconstruction.
LIGHT AND WAVELENGTH COMPENSATION	Since different wavelengths of light have different penetration levels, it is necessary to compensate for the light, for images taken in the Aphotic zone.
HISTOGRAM EQUALIZATION	Histogram of an image is its tonal distribution representation in graphical form.

3. Comparison of Existing Methods

3.1.Deep-WaveNet Method[4]

WaveNet is the algorithm which works well with sinusoidal waves and has a very wide usage area but when it comes to underwater light problems, the algorithm does not work well enough to see details and textures.

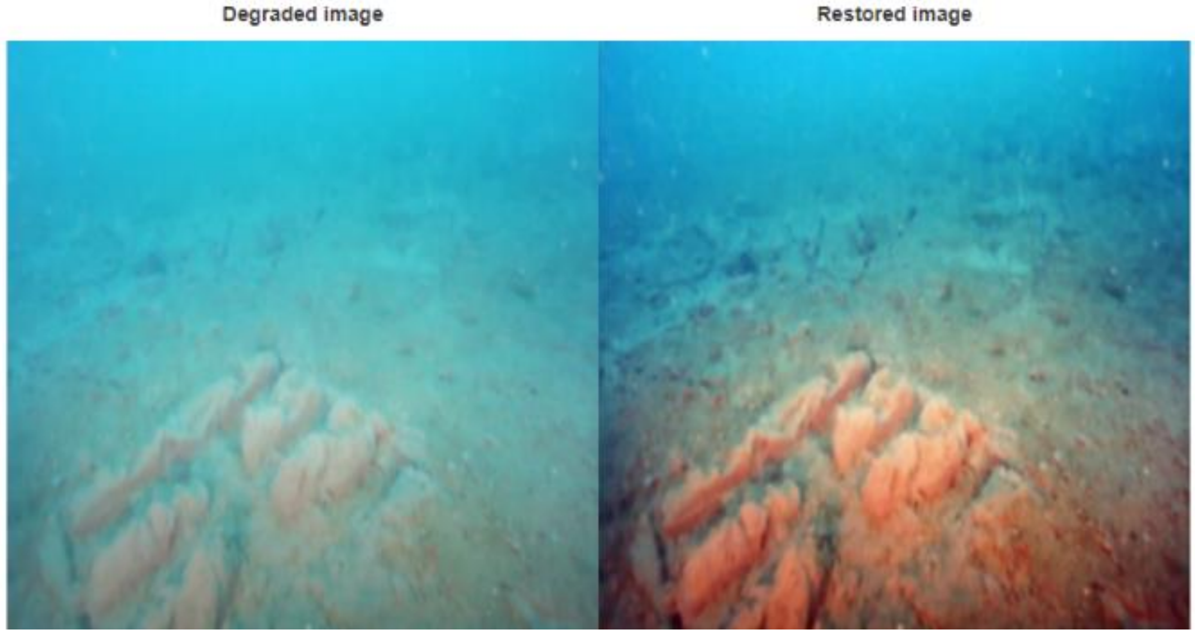

Figure 2: Sample0 with Deep- WaveNet

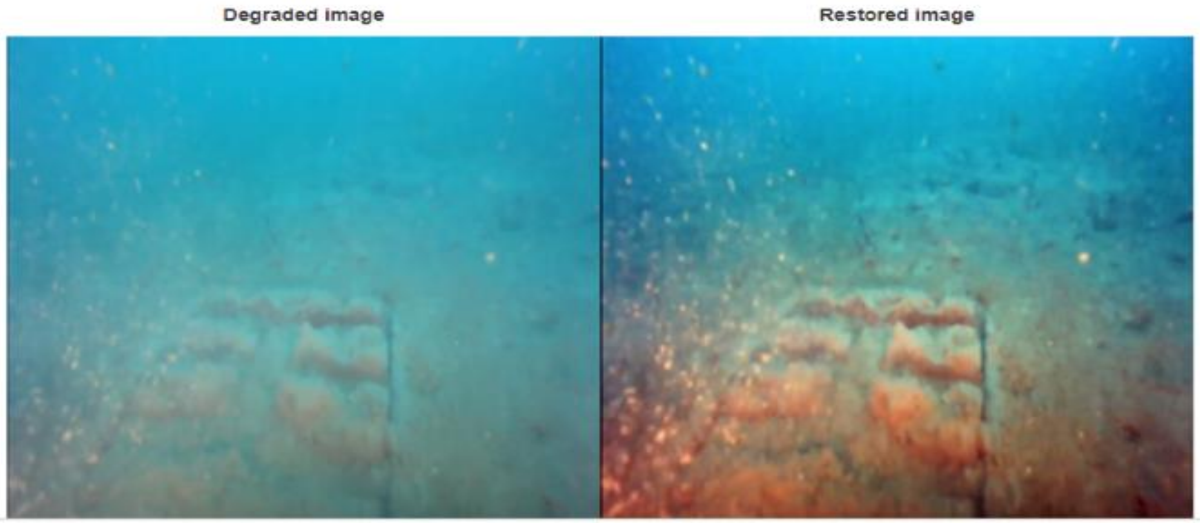

Figure 3: Sample1 with Deep WaweNet

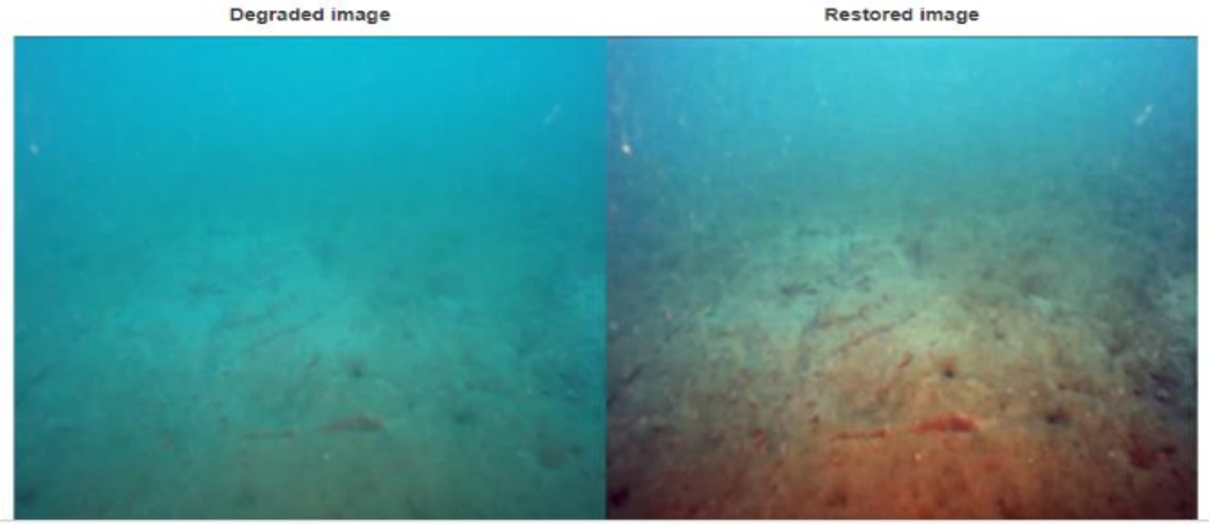

Figure 4: Sample2 with Deep WaveNet

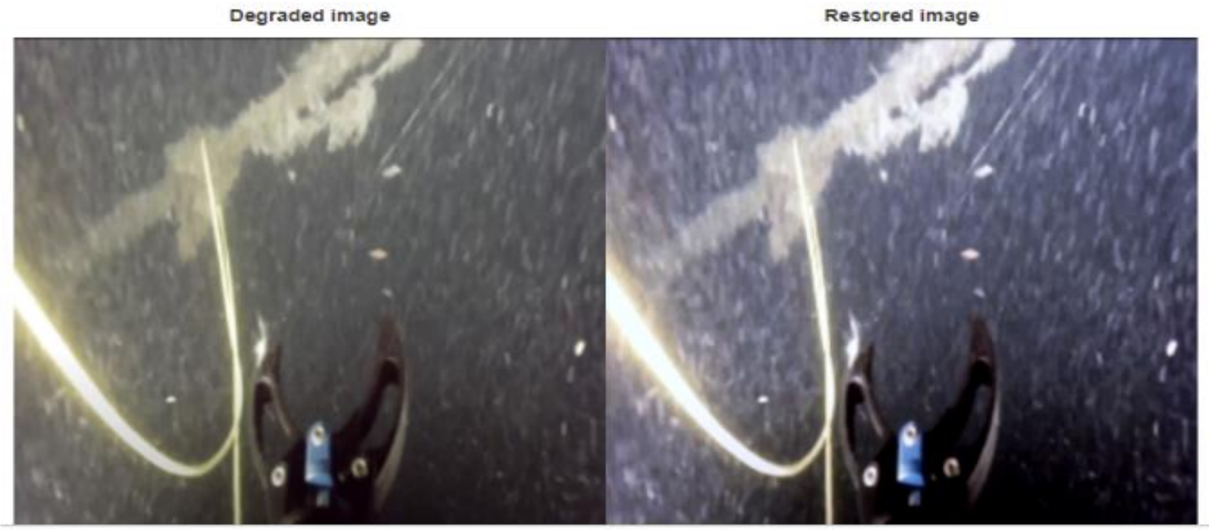

Figure 5: Sample3 with Deep WaveNet

Figure 6: Train0 with Deep WaveNet

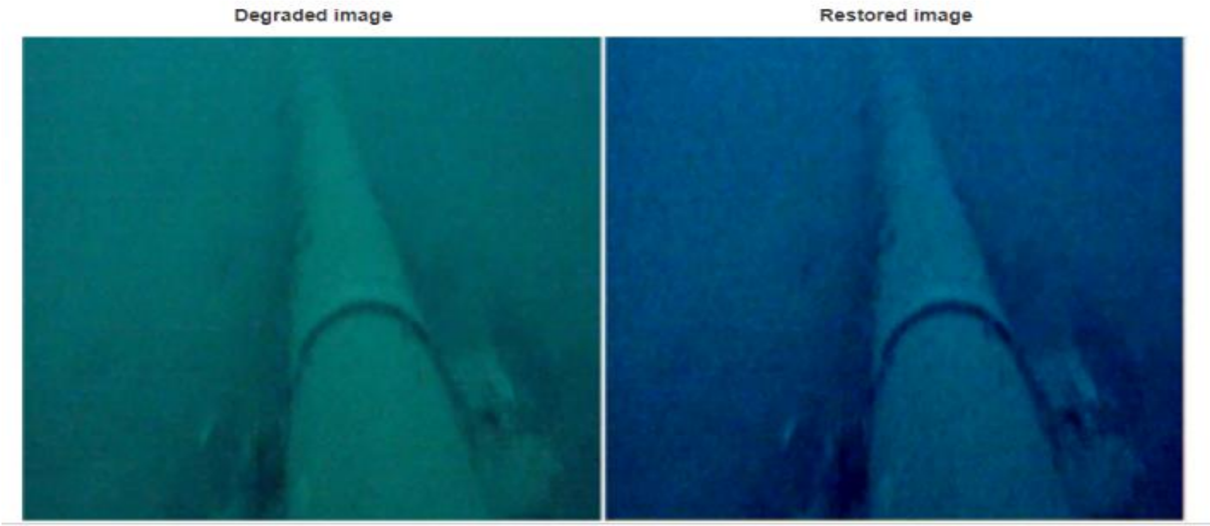

Figure 7: Train1 with Deep WaveNet

Figure 8: Train2 with Deep WaveNet

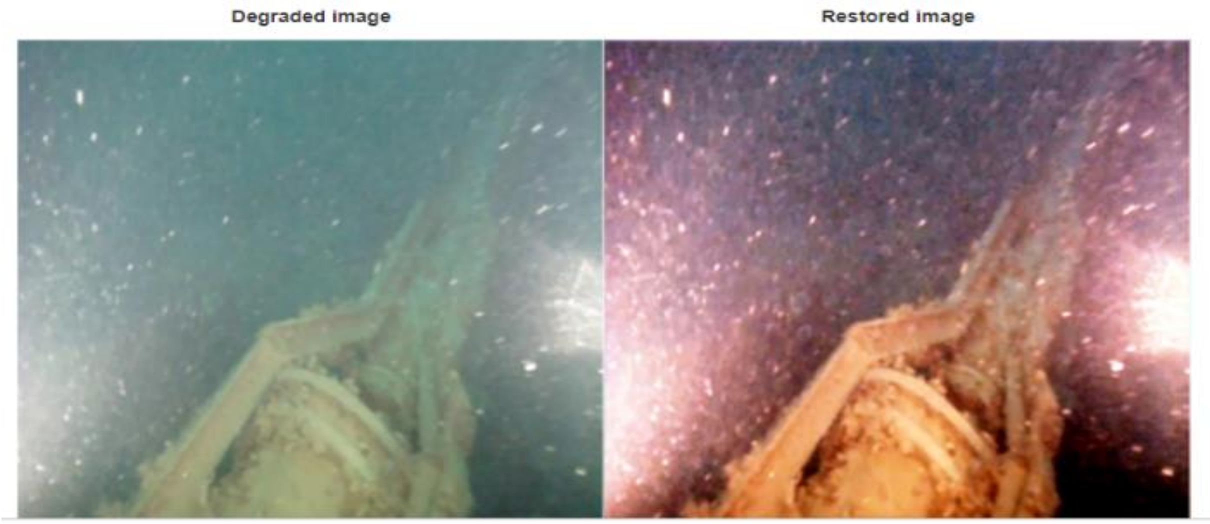

Figure 9: Train3 with Deep WaveNet

3.2. Single Image Dehazing Method by He-Zhang [5]

He-Zhang's method works well if there is light because they are using enhancement approaches. To see details is not enough however it is satisfyingly sharp to use some other methods after itself.

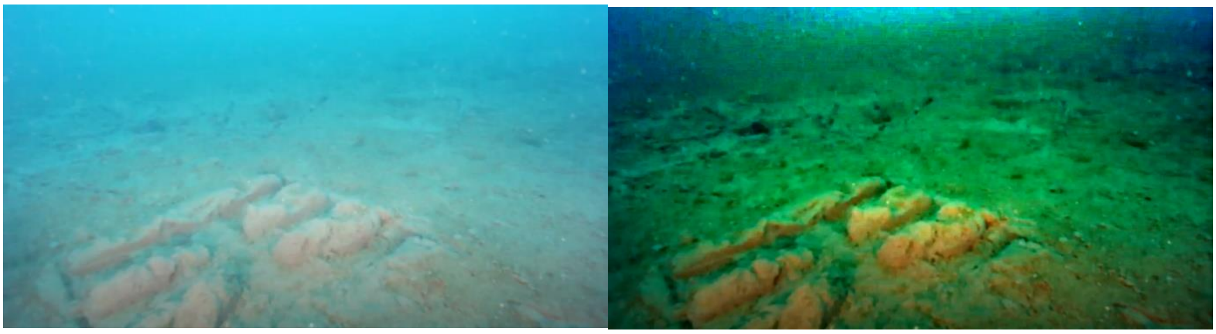

Figure 10: Sample0 with Single Image Dehazing Method by He-Zhang

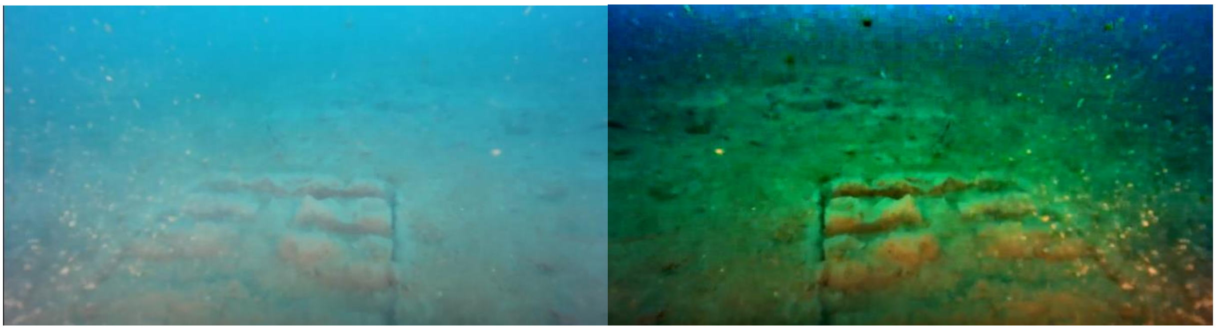

Figure 11: Sample1 with Single Image Dehazing Method by He-Zhang

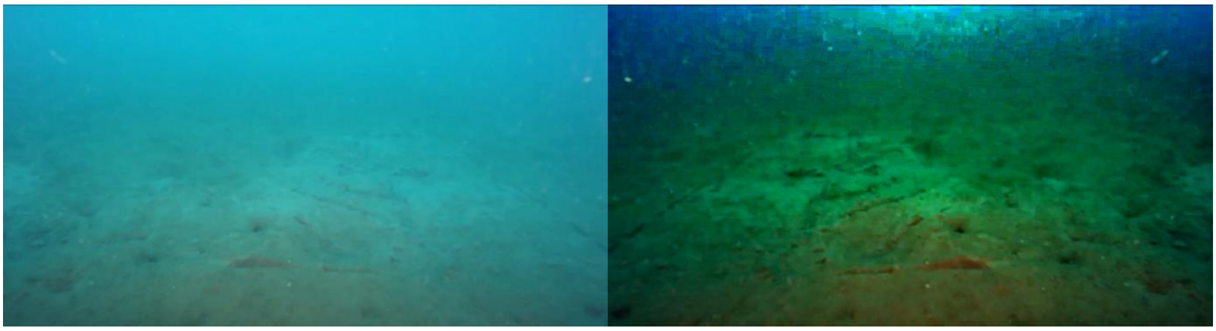

Figure 12: Sample2 with Single Image Dehazing Method by He-Zhang

Figure 13: Sample3 with Single Image Dehazing Method by He-Zhang

Figure 14: Train0 with Single Image Dehazing Method by He-Zhang

Figure 15: Train1 with Single Image Dehazing Method by He-Zhang

Figure 16: Train2 with Single Image Dehazing Method by He-Zhang

Figure 17: Train3 with Single Image Dehazing Method by He-Zhang

3.3. Fusion Image Dehazing by Utkarsh-Deshmukh [6]

Single image fusion methods need light to work but if there is not enough light there is no change as you can see below.

Figure 18: Sample0 with Fusion Image Dehazing by Utkarsh-Deshmukh

Figure 19: Sample1 with Fusion Image Dehazing by Utkarsh-Deshmukh

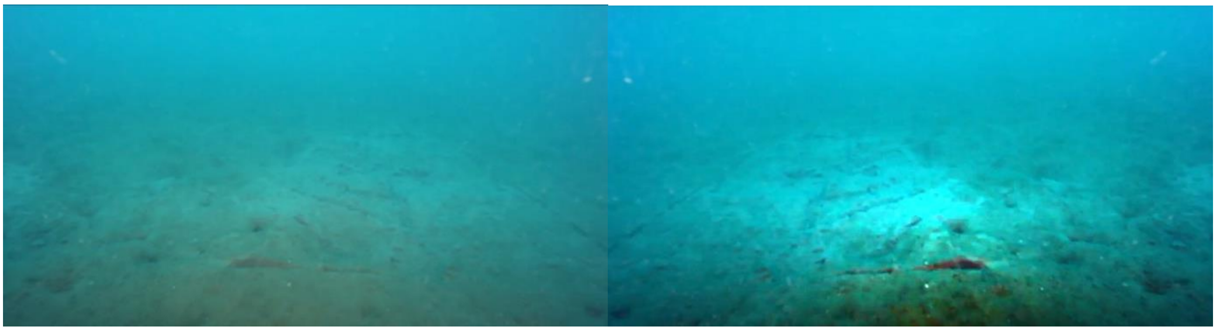

Figure 20: Sample2 with Fusion Image Dehazing by Utkarsh-Deshmukh

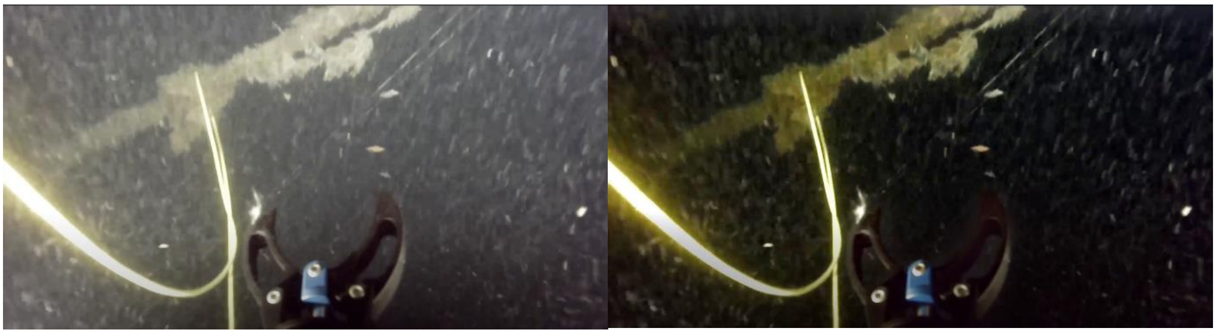

Figure 21: Sample3 with Fusion Image Dehazing by Utkarsh-Deshmukh

Figure 22: Train0 with Fusion Image Dehazing by Utkarsh-Deshmukh

Figure 23: Train1 with Fusion Image Dehazing by Utkarsh-Deshmukh

Figure 24: Train2 with Fusion Image Dehazing by Utkarsh-Deshmukh

Figure 25: Train with Fusion Image Dehazing by Utkarsh-Deshmukh

3.4. Underwater Image Color Restoration – ULAP Method[7]

ULAP is one of the well-known Color Restoration methods. Even it gives high quality results in its paper, the results with the given images are not restored enough to recognize details.

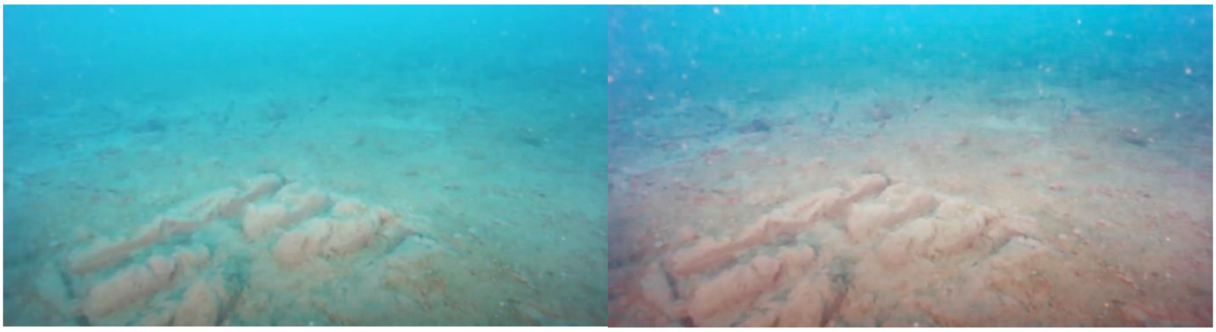

Figure 26: Sample0 with ULAP

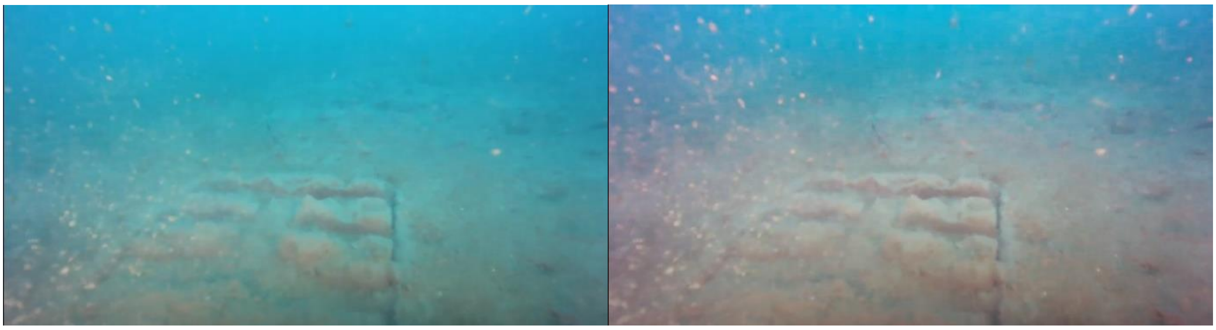

Figure 27: Sample1 with ULAP

Figure 28: Sample2 with ULAP

Figure 29: Sample3 with ULAP

Figure 30: Train0 with ULAP

Figure 31: Train1 with ULAP

Figure 32: Train2 with ULAP

Figure 33: Train3 with ULAP

3.5. Underwater Image Enhancement- Rayleigh Distribution [8]

Rayleigh method has a mathematical background, and the reason why is to try to make a distribution of color balance. But as it seems, it did not work.

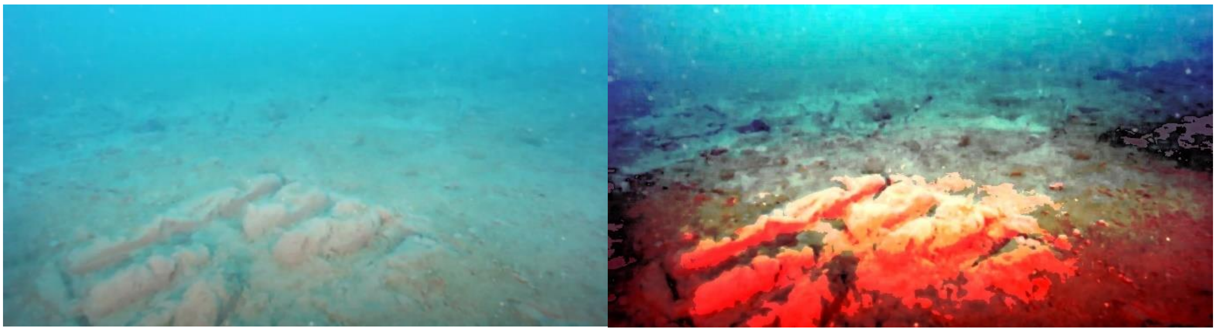

Figure 34:Sample0 with Rayleigh Distribution

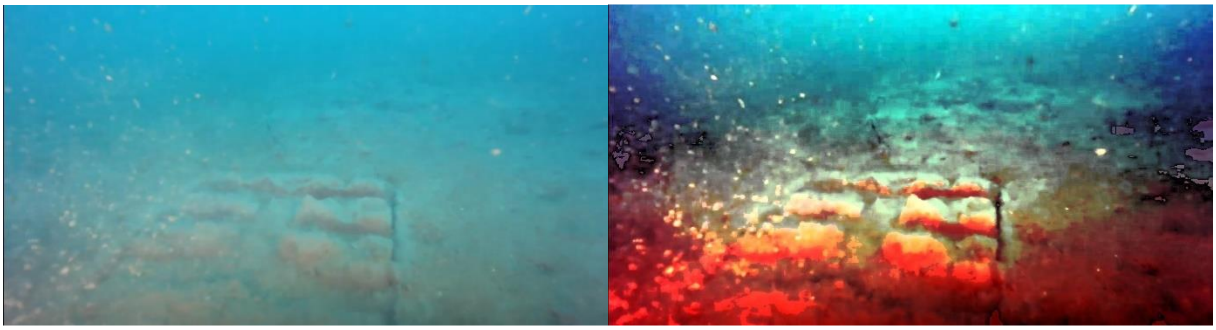

Figure 35: Sample1 with Rayleigh Distribution

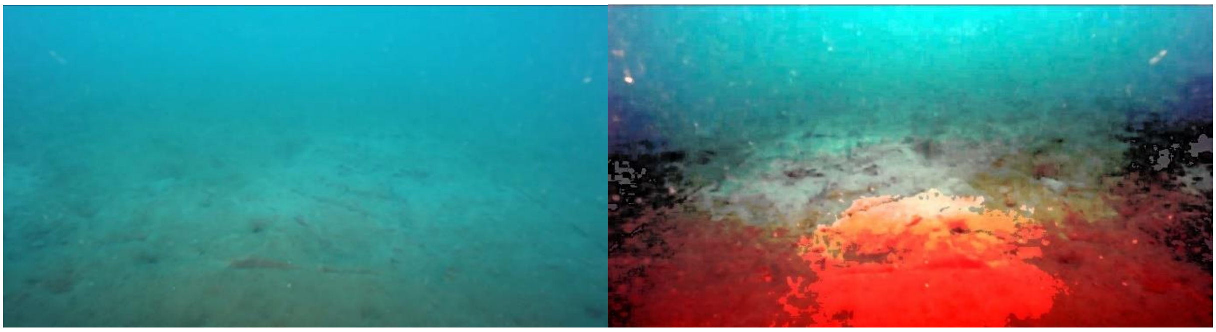

Figure 36: Sample2 with Rayleigh Distribution

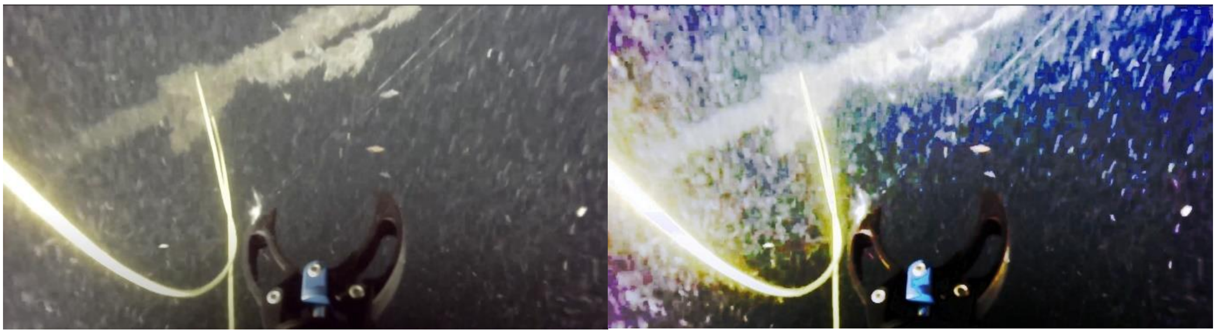

Figure 37: Sample3 with Rayleigh Distribution

Figure 38: Train0 with Rayleigh Distribution

Figure 39: Train1 with Rayleigh Distribution

Figure 40: Train2 with Rayleigh Distribution

Figure 41: Train3 with Rayleigh Distribution

3.6. Underwater Image Enhancement- RGHS[9]

RGHS method is another well-known enhancement method, but it needs light to improve image quality. So, it is not suitable for these kinds of images because of the lack of light.

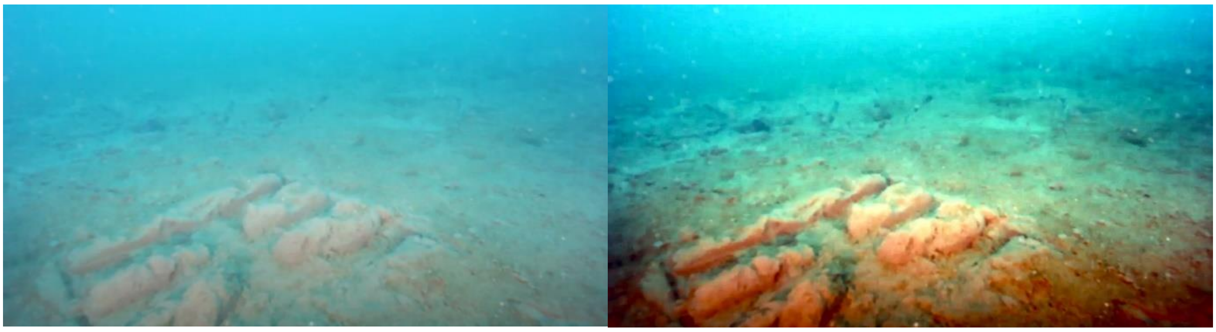

Figure 42: Sample0 with RGHS

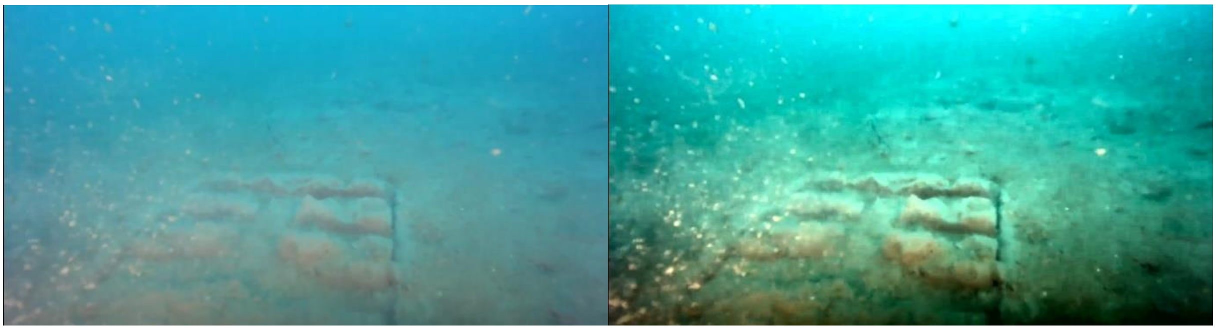

Figure 43: Sample1 with RGHS

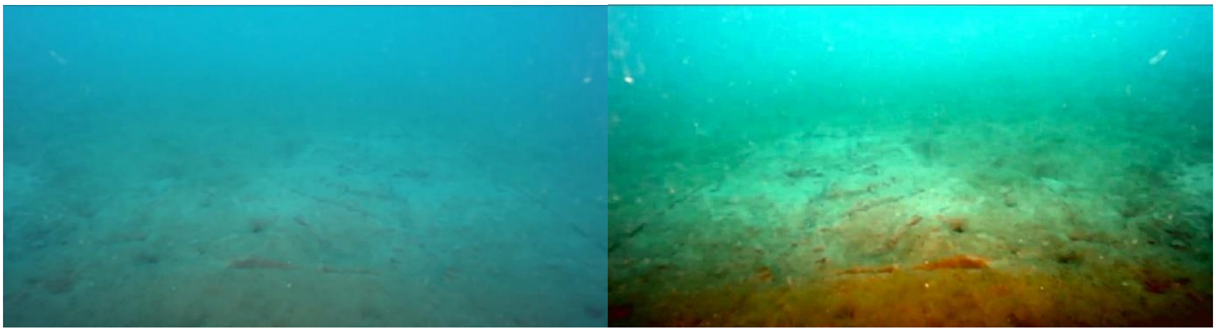

Figure 44: Sample2 with RGHS

Figure 45: Sample3 with RGHS

Figure 46: Train0 with RGHS

Figure 47: Train1 with RGHS

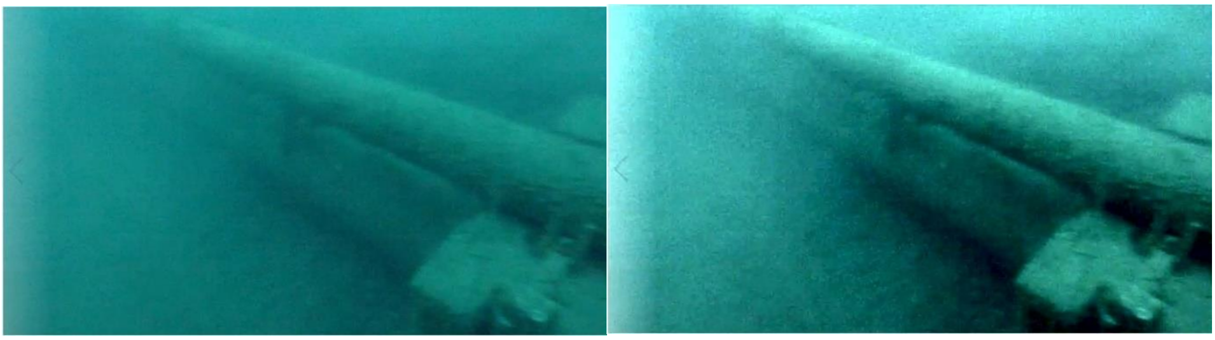

Figure 48: Train2 with RGHS

Figure 49: Train3 with RGHS

3.7. Underwater Image Color Restoration- GBDehazeRCorrection [10]

GBDehazeRCorrection method is developed to balance underwater light propagation and boosts the red channel of images. It could work if there is an additional histogram equalization.

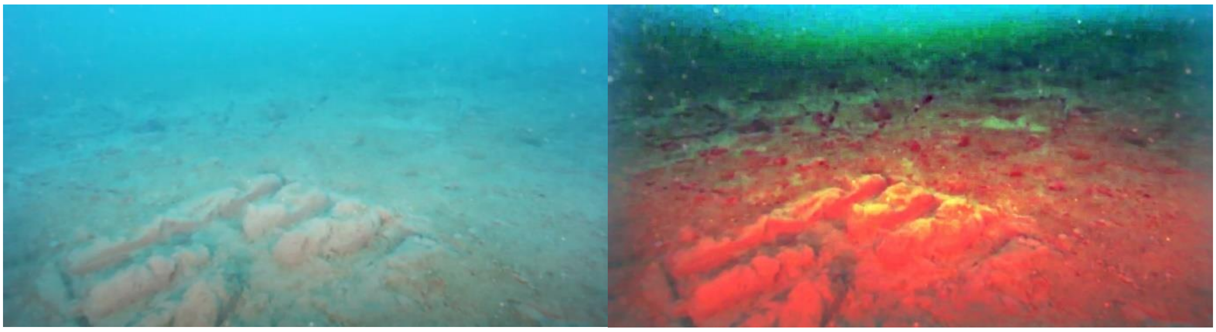

Figure 50: Sample0 with GBDehazeRCorrection

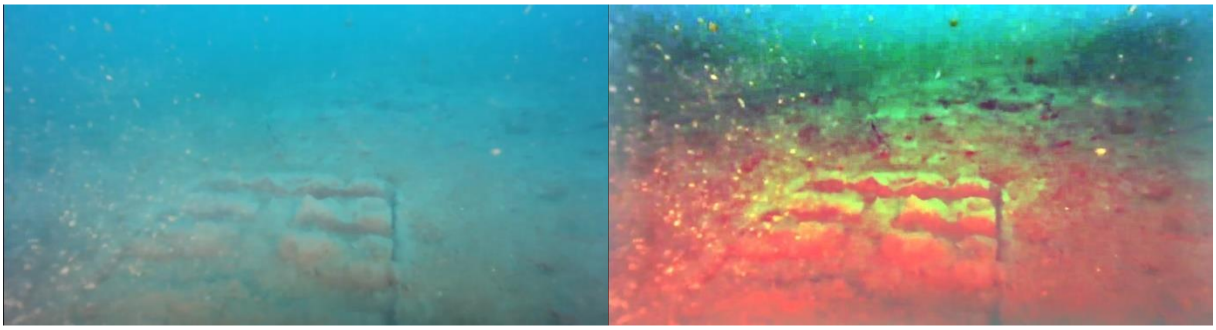

Figure 51: Sample1 with GBDehazeRCorrection

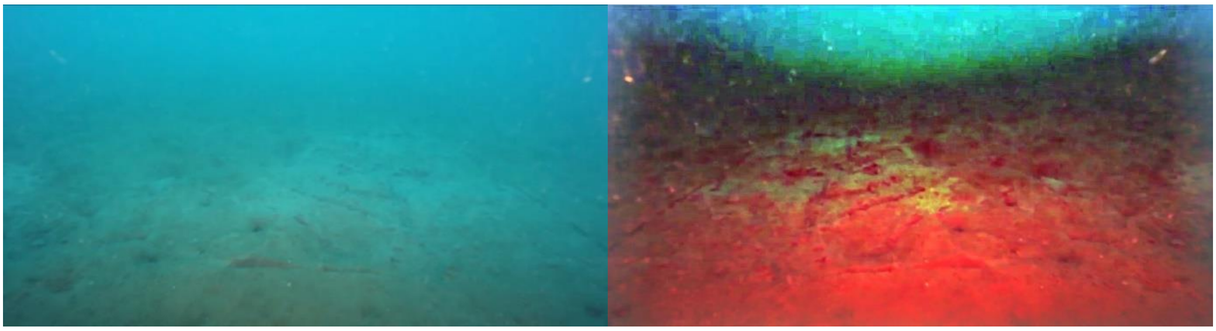

Figure 52: Sample2 with GBDehazeRCorrection

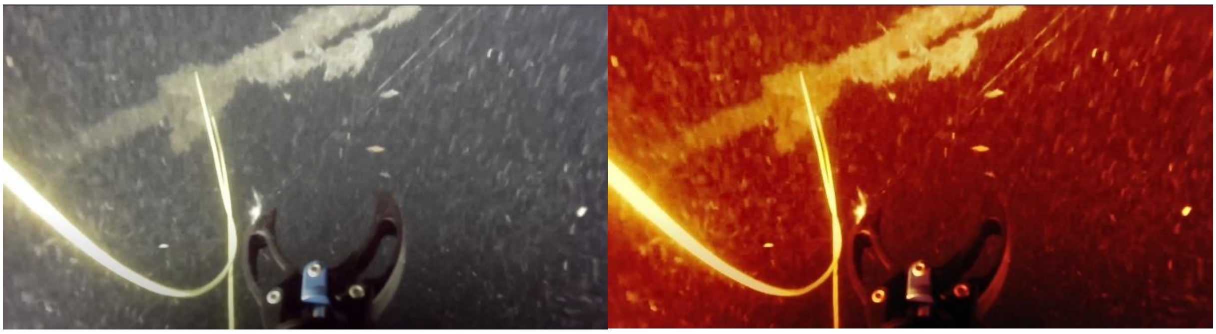

Figure 53: Sample3 with GBDehazeRCorrection

Figure 54: Train0 with GBDehazeRCorrection

Figure 55: Train1 with GBDehazeRCorrection

Figure 56: Train2 with GBDehazeRCorrection

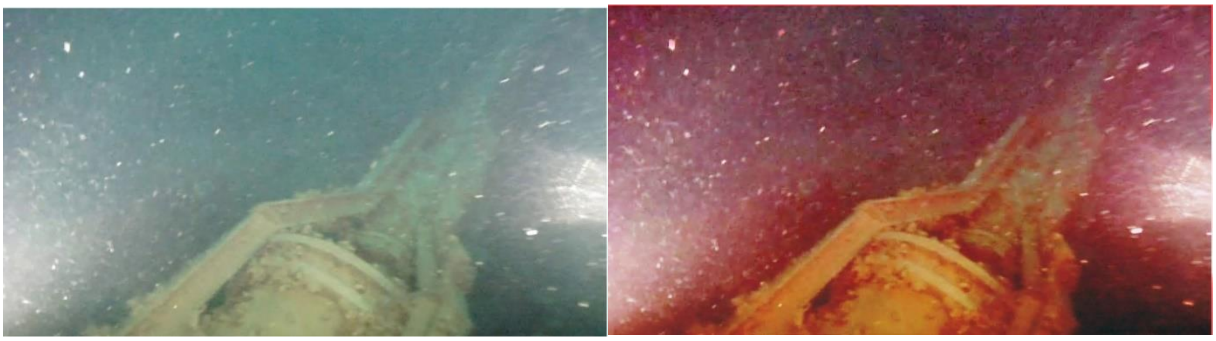

Figure 57: Train3 with GBDehazeRCorrection

3.8. Underwater Image Color Restoration- UIM Method [11]

UIM method is a basic enhancement method, but they preferred to use a two-step algorithm that makes the color balanced, and the image sharpened. As it seems, it worked.

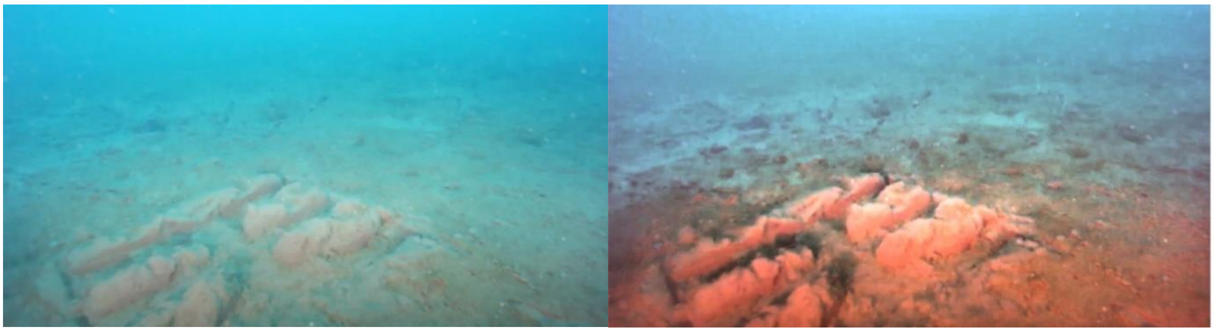

Figure 58: Sample0 with UIM

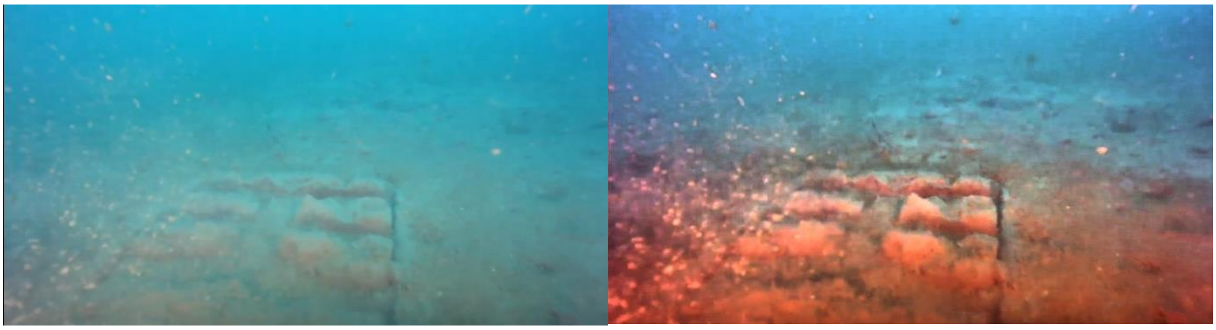

Figure 59: Sample1 with UIM

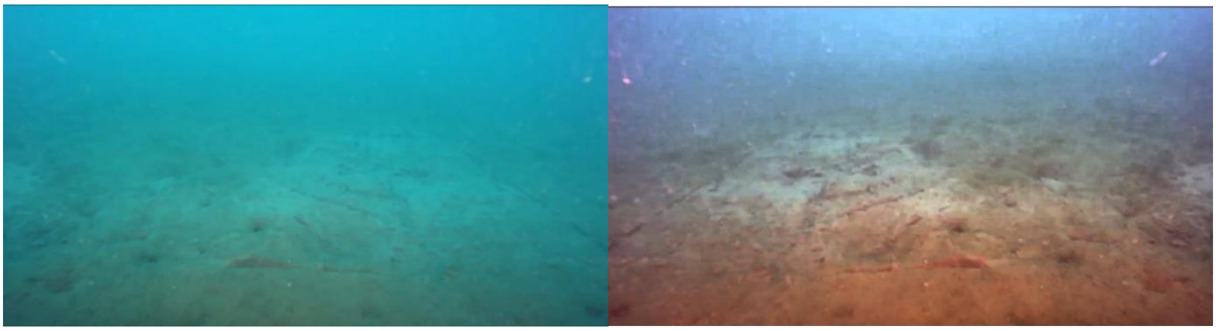

Figure 60: Sample2 with UIM

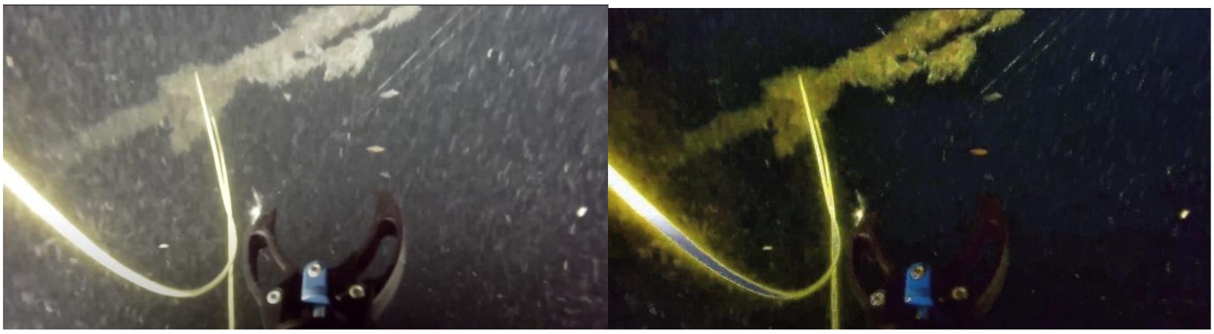

Figure 61: Sample3 with UIM

Figure 62: Train0 with UIM

Figure 63: Train1 with UIM

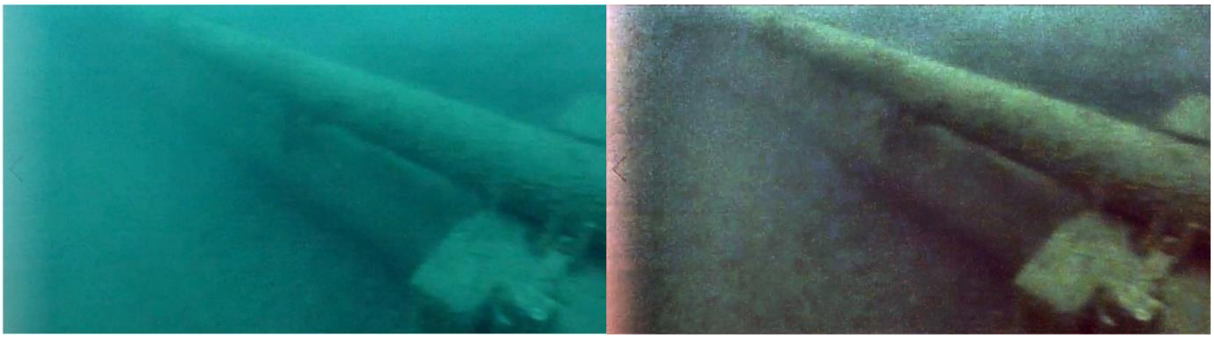

Figure 64: Train2 with UIM

Figure 65: Train3 with UIM

3.9. Simultaneous Enhancement and Super-Resolution (SESR) [12]

SESR method can be acceptable for underwater conditions and promises super-resolution. However, the enhancement part of the algorithm needs improvements for Searover's operations.

Figure 66: Sample0 with SESR

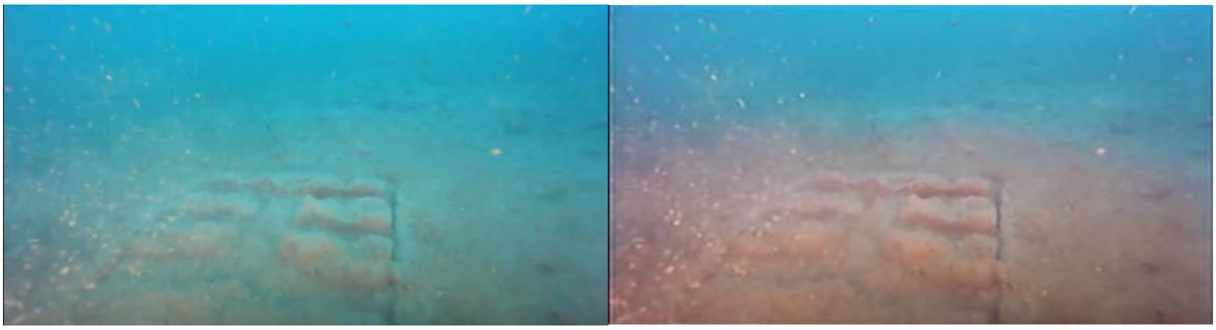

Figure 67: Sample1 with SESR

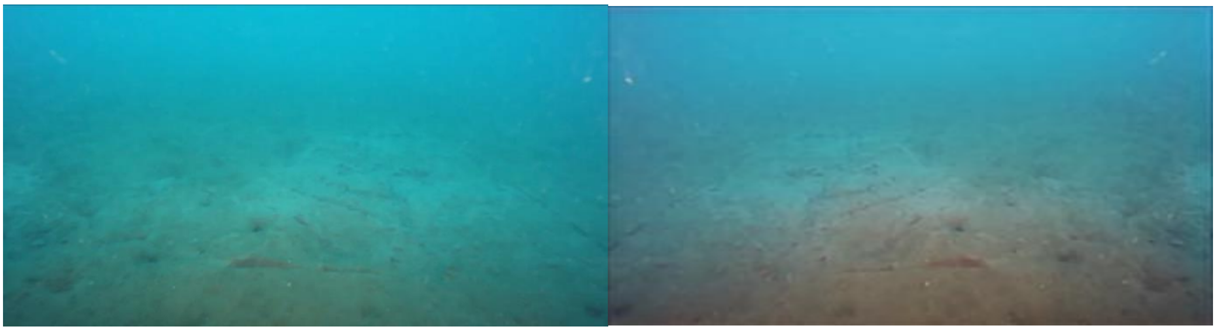

Figure 68: Sample2 with SESR

Figure 69: Sample3 with SESR

Figure 70: Train0 with SESR

Figure 71: Train1 with SESR

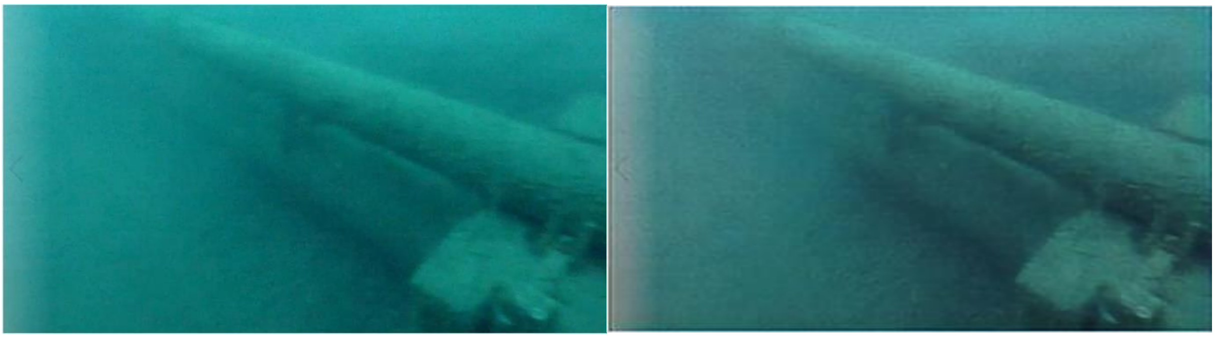

Figure 72: Train2 with SESR

Figure 73: Train3 with SESR

3.10. Color Balance and Fusion for Underwater Image Enhancement [13]

Most of the color balance algorithms are used with fusion to stitch the original and balanced images to not lose details on the image. This algorithm is one of the examples of these methods, and generally the results have good quality.

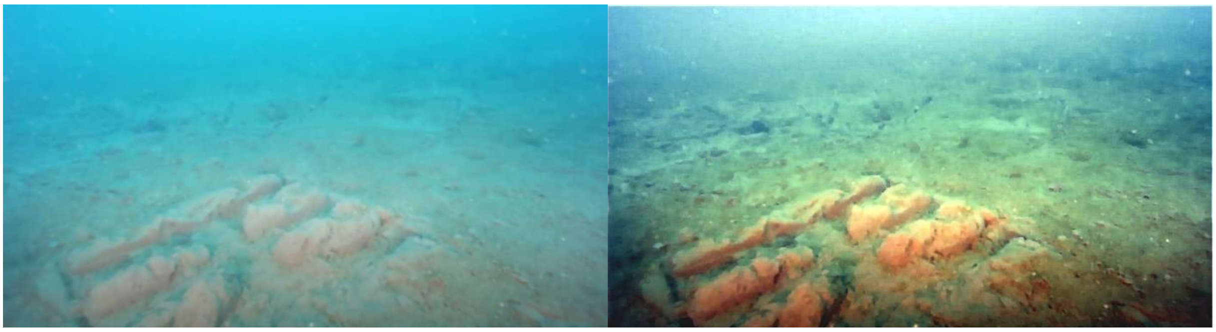

Figure 74: Sample0 with Color Balance and Fusion

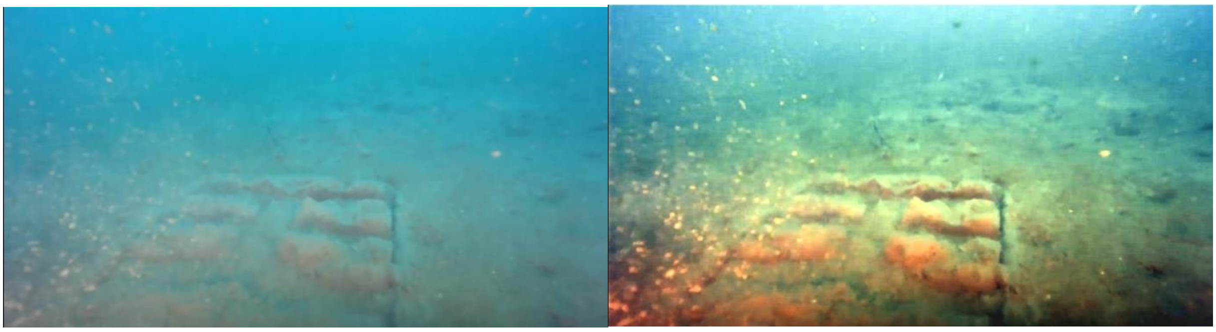

Figure 75: Sample1 with Color Balance and Fusion

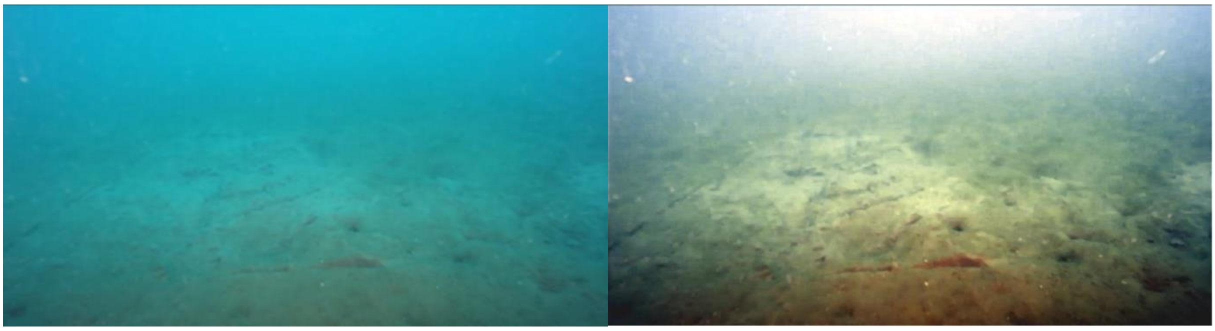

Figure 76: Sample2 with Color Balance and Fusion

Figure 77: Sample3 with Color Balance and Fusion

Figure 78: Train0 with Color Balance and Fusion

Figure 79: Train1 with Color Balance and Fusion

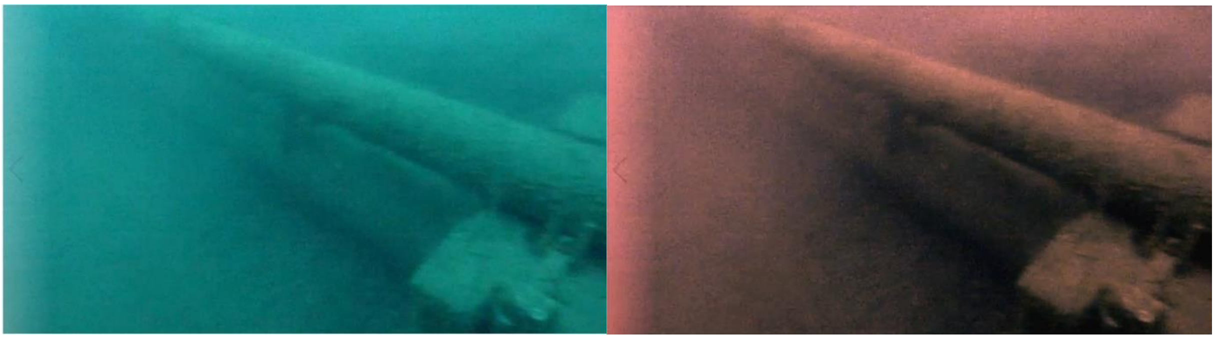

Figure 80: Train2 with Color Balance and Fusion

Figure 81: Train3 with Color Balance and Fusion

3.11. Underwater Image Fusion [14]

Single image fusion algorithms are not working for deep subsea conditions. Also, this algorithm makes details clear but there is no color restoration.

Figure 82: Sample0 with Fusion

Figure 83: Sample1 with Fusion

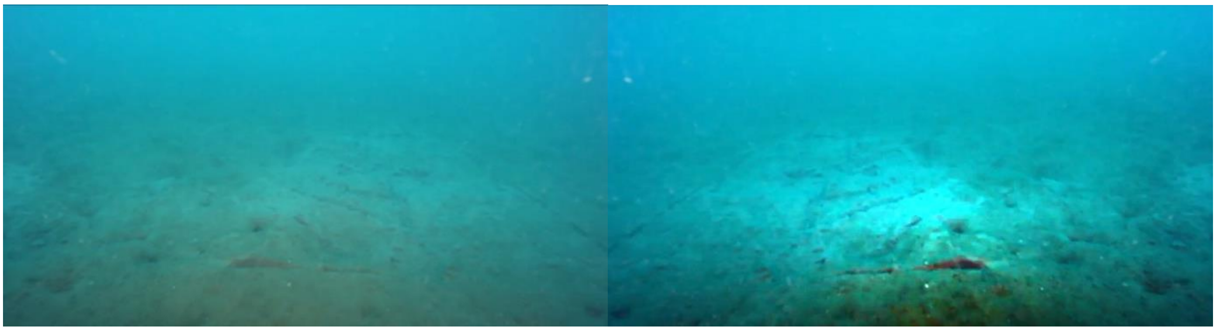

Figure 84: Sample2 with Fusion

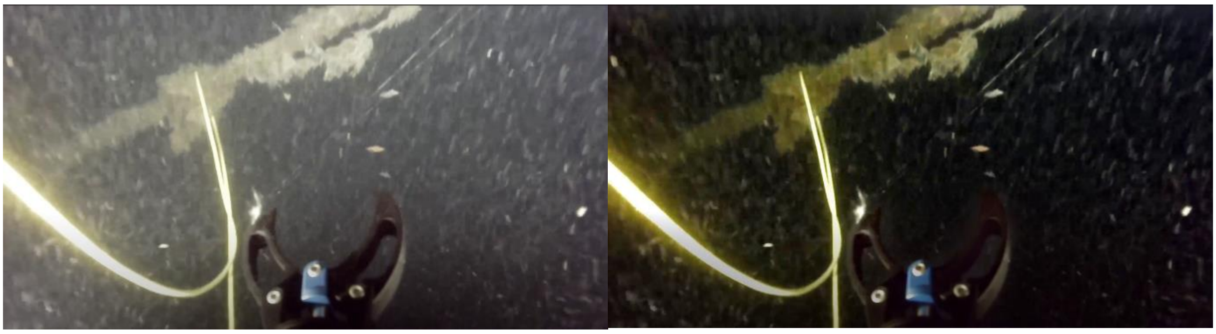

Figure 85: Sample3 with Fusion

Figure 86: Train0 with Fusion

Figure 87: Train1 with Fusion

Figure 88: Train2 with Fusion

Figure 89: Train3 with Fusion

3.12.A Hybrid Framework for Underwater Image Enhancement [15]

This Hybrid Framework can be thought as a recursive algorithm because it uses the different enhanced versions of original images iteratively to achieve best result.

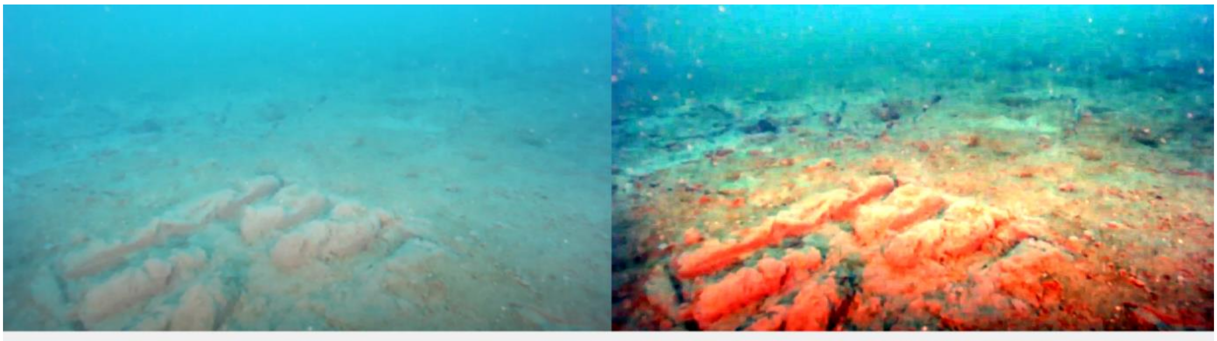

Figure 90: Sample0 with Hybrid Framework

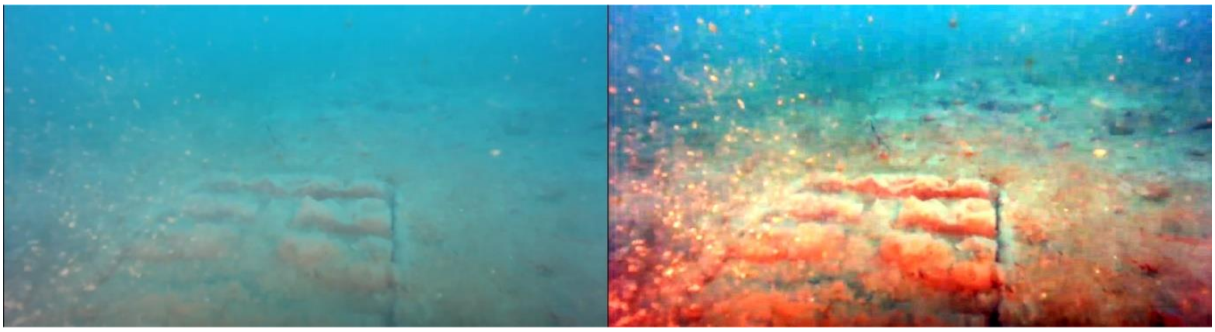

Figure 91: Sample1 with Hybrid Framework

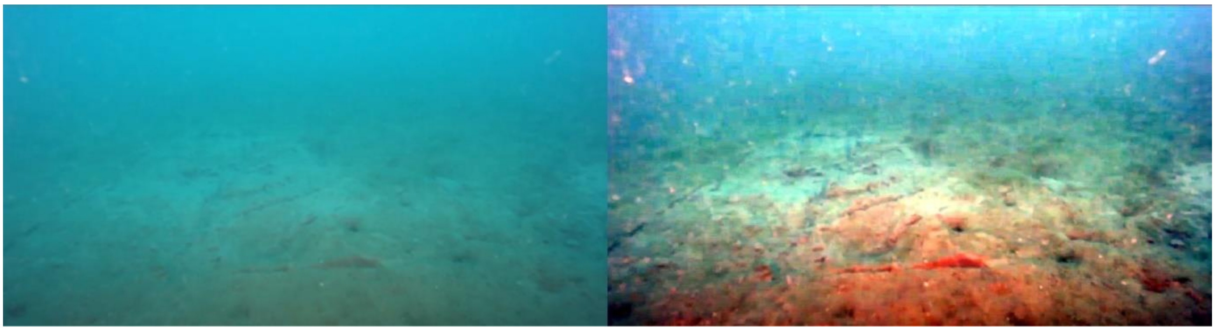

Figure 92: Sample2 with Hybrid Framework

Figure 93: Sample3 with Hybrid Framework

Figure 94: Train0 with Hybrid Framework

Figure 95: Train1 with Hybrid Framework

Figure 96: Train2 with Hybrid Framework

Figure 97: Train3 with Hybrid Framework

Between the whole twelve algorithms, this implementation gave the best results according to the color, details and overall quality of the image regarding to standards.

4. Suggested Algorithm

While studying the implementation, for Underwater Image Processing, output of A Hybrid Framework for Underwater Image Enhancement application is the most successive algorithm compared to others. After a detailed look up for the code, I realized that, using this method after Image Sharpening with Signal Processing and Histogram Stretching for Color Balancing would be more sufficient.

5. Discussion

After studying and implementing the applications that I mentioned on Comparison of Existing Methods, none of them solves the Underwater Image Dehazing problem completely. Because of that, it can be discussed under two titles. One is Software Side and the other is Hardware Side.

5.1.Software Side

For the current stage of Searover, there is an application that I mentioned at the suggested algorithm that has a potential to be used on real time operations after adapting the algorithm without changing any hardware on the ROV. In addition, A Hybrid Framework for Underwater Image Enhancement application is giving us the closest results with respect to Operational Neural Networks, without modifying the scale of the image.

For Research and Development, before color correction and image enhancement, sharpness enhancement is a must for post-Operations. The common Image Dehazing applications are built on convolutional image processing techniques, but they are not effective while working on neighbor pixels without sharpening.

5.2.Hardware Side

First of all, Technical Outputs lack light. A good lighting upgrade for both Operational and Post-Operational studies is a good solution. Also, binocular camera upgrades can improve the streamed image via doing Multiscale Fusion techniques for real time operations and recording more data to evaluate for post-Operations. However, to achieve this, the ROV needs a more powerful and compatible SoC controller that is specialized for Image Processing, like accelerated with CUDA Architecture, Nvidia's Jetson Series [16] ARM Development Boards.

My humble opinion, except white lighting, while getting images with only RED, GREEN and BLUE lights from the same scene, and working on four different illuminated images can give more data of which wavelength of light is absorbed by the objects and which wavelength of light is reflected by the objects. With that data, a new approach can be made on Underwater Image Dehazing techniques. Because most of the details are coming from blue wavelength but not from red wavelength while the scene is not illuminated. Also building a mini artificial sub-sea aquarium simulation can speed up the Underwater Image Processing studies.

Except that, for Underwater Image Processing, developing a new camera system can be thought for Underwater Operations. That will increase the brand value of Searover.

6. Conclusion

After a deep search on Underwater Image Dehazing, I implemented twelve different implementations that have widely different approaches to achieve. The common and main weakness is all of the works are developed for shallow waters that are below 10 meters from sea level, but Observer PRO's achievement is operating its objectives below 200 meters that means only wavelengths of blue color can pass through that level and there is not enough light to operate below that deepness. To improve the quality of Operational and Post-Operational images, suggested improvements in discussion are becoming viable. Except that, developing the suggested image dehazing application, can be suitable for the post-Operations without changing any hardware.

7. References

[1] Lu, H, Li, Y, Zhang, Y, et al. Underwater optical image processing: a comprehensive review. Mobile Net Appl 2017; 22: 1204–1211.

[2] Li, C, Member, S, Guo, J, et al. Underwater image enhancement by dehazing with minimum information loss and histogram distribution prior. IEEE Transact Image Process 2016; 25(12): 5664–5677.)

[3] Schettini, R, Corchs, S. Underwater image processing: state of the art of restoration and image enhancement methods. EURASIP J Adv Sign Process 2010; 2010: 746052.

[4] Prasen Kumar Sharma, Ira Bisht, and Arijit Sur. 2018. Wavelength-based Attributed Deep Neural Network for Underwater Image Restoration. J. ACM 37, 4, Article 111 (August 2018), 21 pages. https://doi.org/10.1145/ 1122445.1122456

[5] Jin-Bao Wang, Ning He, Lu-Lu Zhang, Ke Lu,Single image dehazing with a physical model and dark channel prior,Neurocomputing,Volume 149, Part B,2015,Pages 718-728,ISSN 0925-2312, https://doi.org/10.1016/j.neucom.2014.08.005.

[6] *Gaofeng Meng, Ying Wang, Jiangyong Duan, Shiming Xiang, Chunhong Pan*; Proceedings of the IEEE International Conference on Computer Vision (ICCV), 2013, pp. 617-624

[7] Wenfeng Zhao, Shenghui Rong, Tengyue Li, Xueting Cao, Yongbin Liu, and Bo He "Underwater single image enhancement based on latent low-rank decomposition and image fusion", Proc. SPIE 11720, Twelfth International Conference on Graphics and Image Processing (ICGIP 2020), 1172018 (27 January 2021); https://doi.org/10.1117/12.2589359

[8] Abdul Ghani, A.S., Mat Isa, N.A. Underwater image quality enhancement through composition of dual-intensity images and Rayleigh-stretching. SpringerPlus 3, 757 (2014). https://doi.org/10.1186/2193-1801-3-757

[9] Dongmei Huang, Yan Wang, Wei Song, Jean Sequeira, Sébastien Mavromatis. Shallow-water Image Enhancement Using Relative Global Histogram Stretching Based on Adaptive Parameter Acquisition. 24th International Conference on Multimedia Modeling - MMM2018, Feb 2018, Bangkok, Thailand. ffhal-01632263f

[10] C. Li, J. Quo, Y. Pang, S. Chen and J. Wang, "Single underwater image restoration by blue-green channels dehazing and red channel correction," 2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 2016, pp. 1731-1735, doi: 10.1109/ICASSP.2016.7471973.

[11] X. Fu, Z. Fan, M. Ling, Y. Huang and X. Ding, "Two-step approach for single underwater image enhancement," 2017 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS), 2017, pp. 789-794, doi: 10.1109/ISPACS.2017.8266583.

[12] Islam, Md Jahidul & Luo, Peigen & Sattar, Junaed. (2020). Simultaneous Enhancement and Super-Resolution of Underwater Imagery for Improved Visual Perception. 10.15607/RSS.2020.XVI.018.

[13] 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.

[14] C. Ancuti, C. O. Ancuti, T. Haber and P. Bekaert, "Enhancing underwater images and videos by fusion," 2012 IEEE Conference on Computer Vision and Pattern Recognition, 2012, pp. 81-88, doi: 10.1109/CVPR.2012.6247661.

[15] Xinjie Li, Guojia Hou, Lu Tan and Wanquan Liu, "A hybrid framework for underwater image enhancement," IEEE Access, vol. 8, pp. 197448-197462, 2020.

[16] https://www.nvidia.com/tr-tr/autonomous-machines/embedded-systems/