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COMPARISON OF UNDERWATER IMAGE PROCESSING AND RESTORATION USING SEA-THRU AND HAZE-LINES ALGORITHM

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Abstract

The picture which is taken without good lighting will have a shortcoming such as low contrast and discoloration. The lack of light received by objects is usually affected by the position of the object that might be out of camera range or disturbed by fog or water. In this research, we compare image processing and restoration algorithms to restore underwater images that have low contrast and discoloration compared to the real object. The sample images that we use in this restoration process are taken from the Sea-Thru dataset. The results of this research will display the results of the restoration of each algorithm and analyze the comparison of color restoration, transmission restoration, air-light estimation, and counting the RGB channel. With all comparisons, the strengths and weaknesses of the Sea-Thru and Haze-Lines algorithms will be shown, which are the Sea-Thru result is more successful in displaying object colors clearly but still has shortcomings when the angle of sampling image is down, while the Haze-Lines result has more stable in any angles of sampling image.

Keywords: *Sea-Thru, Haze-Lines, restoration, image, underwater*

Introduction

The results of images taken underwater usually have shortcomings in terms of contrast and color. This deficiency is due to the depth of the object and the absorption of light waves by water. The deeper the position of the object from the water level, the object has fewer chances to receive light because the light has been absorbed by the water molecule.

Aside from that, in the water, especially under the sea, there are water organisms such as phytoplankton and algae who carry out photosynthesis and during the process, it absorbs the color spectrum which is brought by light. Therefore, it is necessary to do image restoration. Many methods of image restoration have been developed, including Sea-Thru and Haze-Lines used to reconstruct or color restoration of underwater images.

In research from Akkaynak and Treibitz [1] proposed the Sea-Thru algorithm whose main purpose is to create a physically accurate model to reconstruct underwater images by revising the old model into a new model that has been revised. On the other hand, Haze-Lines from Berman, Levy [2] focuses more on reconstructing foggy images in outdoor images. An underwater photo is the equivalent of outdoor photos covered with thick-colored fog. Therefore, the Haze-Line method must be able to reconstruct the underwater image.

The Sea-Thru algorithm will restore the image by estimating the backscatter using the pixel and calculating the distance or range of the image. However, it is important to note that the further away the camera is from the object, the higher the backscatter value will occur. The way to handle the backscatter is using Dark Channel Prior, which was developed to process images with haze or fog [1].

While in the Haze-Lines algorithm, image restoration is done by checking the contrast between the pixels and observing an image object by counting the number of different colors depending on the size of pixels. Hazy images have been covered with blurry lines or light due to the scattering medium**,** which can change the appearance of true colors ofthe objects where that color will be changed to RGBlines, termed Haze-Lines [2].

We choose to further analyze the Sea-Thru algorithm because this algorithm is still relatively new and the algorithm is focused on underwater image restoration. And the Haze-Lines as a comparison was chosen because this algorithm is the basics of image restorations and most recently, researchers have succeeded in developing a haze-lines algorithm for underwater image restoration. The goal of this research is to discuss the differences in color restoration, transmission restoration, air-light estimation, and RGB channel of image result from the image restoration using these two algorithms**,** so the strengths and weaknesses of each algorithm will be seen andcan be considered for future development of image processing and restoration algorithms.

Literature Review

Image File Format

An image that has been taken using a camera or scanner is unprocessed and it can be called a RAW image. Many DSLR cameras, including Sony cameras used to take pictures of underwater image datasets, can shoot in RAW, whether it be a .raw, .cr2, or .nef. [3] explains that RAW images are the equivalent of a digital negative, meaning that they hold a lot of image information, but still need to be processed in an editor. The RAW picture will be processed into another image file format which is a standardization for encoding information about an image into bits of data for storage. Any program which adheres to the format standard may then open the file and display the image. Some examples of image formats used are TIFF and JPEG.

TIFF or Tagged Image File Format are lossless images files meaning that they do not need to compress or lose any image quality or information, allowing for very highquality images but also larger file sizes. In this underwater dataset [4]. In this research, TIFF will be used as a supporting image for image restoration where each RAW image has one TIFF.

JPG which stands for Joint Photographic Experts Groups is a “lossy” format meaning that the image is compressed to make a smaller file. The compression does create a loss in quality but is generally not noticeable. JPG files are a common format for digital cameras making them ideal for web use and non-professional prints [4]. This type will be used as the output of the Sea-Thru and Haze-Lines algorithm.

Underwater Image Characteristics

a) Water Attenuation

When there is light scattering on the water molecules, light that enters the medium will undergo a process of absorption and scattering, where the absorption process itself is the loss of light on the scattering medium, while scattering is the bending of light in a straight line to the medium it receives [2, 5].

According to Lambert-Beer, the absorption process occurs when the process of releasing a related light intensity occurs with properties of matter that have an exponential dependence on the value of irradiance E at position r, which can be formulated as follows:

$$E(r) = E(O)e^{-cr} \quad (1)$$

The value of c is the total attenuation or light coefficient value in the affected medium, with the total value of light disappearing, which can be calculated from the total scattering and absorption values during the passage of light into the scattering medium. For the coefficient value itself, each medium has a different value and can be seen, for the deepwater ocean, the resulting coefficient value is 0.05m-1, for coastal waters the coefficient value is 0.2m-1, and for waters in the bay it has a value of 0.2m-1. coefficient of 0.33m-1.

It can be assumed that if the medium is isotropic or homogeneous, then the total coefficient value c can be divided into 2 different values, namely a and b, where the value to be obtained to calculate the absorption and scattering effects is

$$E(r) = E(O)e^{-ar}e^{-br} \quad (2)$$

To calculate the total scattering coefficient from the value of b is a superposition of all scattering events that come from each angle whose calculations use the function formula $\beta(\theta)$ where the function formula is responsible for calculating the probability of the direction of light scattering from angle θ, where it is a direction of light that will enter a medium

$$b = 2n\int_{0}^{n} \beta(\theta) sin\theta d\theta \quad (3)$$

Where parameters a, b, c and θ represent the inherent properties of the medium and theoretical knowledge that can make it possible to predict the scattering of light in water.

Color Quality Loss

Based on information from Steiner, Juvela [6], direct illumination losses are primarily caused by the absorption of light in the water volume between the source and subject. The absorption of light in pure water is generally dominated by the interaction of photons with water molecules. As a photon contacts a water molecule, it is absorbed and converted to heat energy. This interaction has a strong dependence on wavelength, with light in the red and violet ends of the spectrum being strongly attenuated while a blue-green region of the visible spectrum has minimal attenuation. This is what gives seawater its strong blue-green appearance.

The deeper the water, the colors that appear will be more refractive. Starting at 3 meters of depth, the red color of the object starts to fade. Then at 5 meters of depth, the orange color of the object will fade, and at 10 meters of depth, the yellow color will fade, while the blue color itself will last a little longer than other colors because basically, the color of the water is dominated by blue and green. In addition, the variation of the incoming light will certainly greatly affect the perception of these colors, which will result in various colors becoming one of the characteristics of an underwater image.

Image Restoration

The purpose of image restoration is to improve the information in an image so that it is easy to read or improve the quality of the image. The underwater image will be processed by image restoration algorithms such as Sea-Thru or Haze-Lines to produce a better image in terms of color quality.

Research from [1] proposed the Sea-Thru algorithm whose main purpose is to create a physically accurate model to reconstruct underwater images by revising the old model into a new model that has been revised. In a simple Sea-Thru model, the formation of an underwater image can be modeled as follows:

$$Ic = Dc + Bc \tag{4}$$

Where c is the RGB channel, Ic is the observed image for the channel, Dc is the direct signal from the scene, and Bc is the backscatter effect.

Meanwhile, research from [5] explains the Haze-Lines algorithm is one of the methods for dehazing images which suffer from low contrast and limited visibility due to haze. Based on research from [2, 7] and [8] the image formation model in fog is generally a linear combination formed by the attenuated beam of the scene and ambient light scattered into the line of sight.

$$I(x) = t(x) \cdot J(x) + [1 - t(x)] \cdot A \tag{5}$$

Where x is the pixel coordinate, I is the observed blurry image (linear sensor response), and J is the actual radiance of the imaged point at x. Atmospheric light A is a single color representing the ambient light in the image area where t = 0.

But this model only applies to images taken during the day, assuming a single atmospheric glow. Whereas at night or in heavy fog, atmospheric light often varies and more complex image formation models must be used. Therefore, the dehazing process should be applied to the radiometrically corrected image to get the best results.

Sea-Thru Algorithm

The Sea-Thru algorithm is a method for reconstructing an image taken from underwater by estimating the backscatter using pixels and distance or range information from the image. The following are the image processing steps applied to this algorithm:

Simplified model

Akkaynak and Treibitz (2019) proposed a more accurate model for underwater image restoration. The underwater imaging model is described as follows:

$$I_c = J_c \exp(-\beta_c^D . z) + B_c^{\infty}(1 - \exp(-\beta_c^B . z)) \tag{6}$$

Imaging range estimation

As β_c^D heavily depends on z we require having a range map of the scene, obtained using structure-from-motion (SFM), which is commonly used underwater. The provided structure-from-motion maps have depths provided in meters.

Backscatter Estimation

Backscatter causes specks of light to appear in the image, it needs to be removed in order to improve the visibility of the image. The backscatter increases exponentially with the range between the camera and the scene. Our approach to estimating the backscatter is similar to Dark Prior Channel (DCP) where we search for the darkest RGB triplets and use them to get an initial estimate of backscatter [1].

However, pixels with depth values that are too large/small become quite noisy, and therefore we can set a minimum cutoff for the depths of colors used in the estimations.

Illuminant Estimation and Color Recovery

The above method only solves the problem of haze caused by scattering. When the backscatter is removed from the original image I, color distortion still exists due to the absorption of light by water. Therefore, a color recovery method is necessary after restoration. After reconstructing the image, we perform white balancing. Sea-Thru uses the Gray World Hypothesis assumption for white balancing.

Algorithm 1: Sea-Thru Underwater Image Restoration

Input: RAW image, Depth image
Output: Color correction image, Transmission correction image

```
Load image and depth map
Estimating backscatter
Finding backscatter coefficients
WHILE accurate reconstruction
    IF Best loss > Max mean loss
        Switch Linear Model
    END IF
END WHILE
Constructing neighborhood map
Refining neighborhood map
Estimating illumination
FOR Max iteration
    Estimate from local color space averaging
END FOR
Estimating wideband attenuation
Reconstructing the image
Globally white balance
RETURN recovered image
```

Haze-Lines Algorithm

Haze-Lines algorithm is one of the methods for dehazing images which suffer from low contrast and limited visibility due to haze. In general, there are 3 steps in Haze-Lines are Veiling-Light Estimation, Transmission Restoration, and Color Restoration [5].

Veiling-Light Estimation

In order to detect the pixels that belong to the veiling-light, the code will apply a linear contrast stretching and then generate an edge map of the scene using the Structured Edge Detection Toolbox with pre-trained model and default parameters. After that, the edge map will be thresholded and the largest connected component found. The pixels belonging to the largest component are classified as veiling-light pixels [9].

Transmission Restoration

The transmission depends on the object's distance z(x) and the water attenuation coefficient for each channel βc.

$$tc(x) = \exp(\beta cz(x)) \tag{7}$$

In the ocean, the attenuation of red colors can be an order of magnitude larger than the attenuation of blue and green. Therefore, as opposed to the common assumption in single image dehazing, the transmission t = (tR; tG; tB) is wavelength-dependent [2].

Color Restoration

On the Haze-Lines algorithm, the color restoration will be performed by implementing 10 water types by Jerlov (1976) which are I, IA, IB, II, III, C1, C3, C5, C7, C9.

Algorithm 2: Haze-Lines Underwater Image Restoration

Input: RAW image
Output: Color correction image, Transmission correction image

```
FOR each image on dir images
    IF the image is raw THEN
        Detect the DNG file
        Convert DNG file to linear image
        Contrast adjustment linear image
        Reduce the resolution of the image
    ELSE
        Contrast adjustment of image
    END IF
    Prepare directory for output
    IF the image is raw THEN
        Convert linear image to RGB image
        Contrast adjustment RGB image
    END IF
    Estimate veiling light
    FOR each water type
        Implementation water type on the linear image
        Calculate compensated distances from veiling-light in RGB space
        Estimate initial transmission
        Estimate radius
        Estimate transmission
        Restore image
    END FOR
    Return the image that best adheres to the Gray-World assumption on pixels
END FOR
```

Methodology

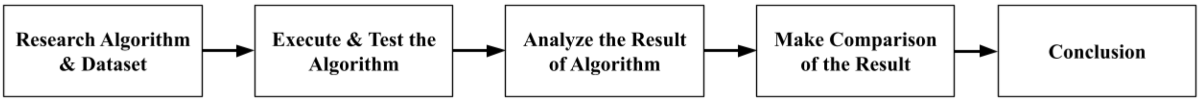


Figure 1. Methodology step in this research

In this research, we decided to explore underwater image restoration because based on our research of previous information, we found that underwater images still have a shortcoming that has not been well covered. The first step for this research is finding the algorithm and dataset to test. There are many algorithms or methods that have been developed, and we choose to work with the Sea-Thru algorithm and Haze-Lines algorithm. The Dataset itself is taken from the Sea-Thru Dataset [1].

The dataset will be processed with the Sea-Thru and Haze-Lines algorithm source code so we can see the result and do analysis to show the comparison of the algorithms. With this step, it can be said that this research uses a combination research method with a quantitative and quality approach. After the comparison, we can draw conclusions, so the advantages and disadvantages of each algorithm will be seen.

Results and Discussions

Sampling Images

The sampling images were taken from the Sea-Thru dataset. This dataset has more than 1,100 images from two optically different water bodies, but in this research, we used 2 categories of datasets which are D1 and D3 which are both taken using Sony α7R Mk III with Sony FE 16-35mm f/2.8GM. The difference is D1 contains images of reef scenes with a depth of 10m, while D3 contains images of reef scenes with a depth of 4m [1].

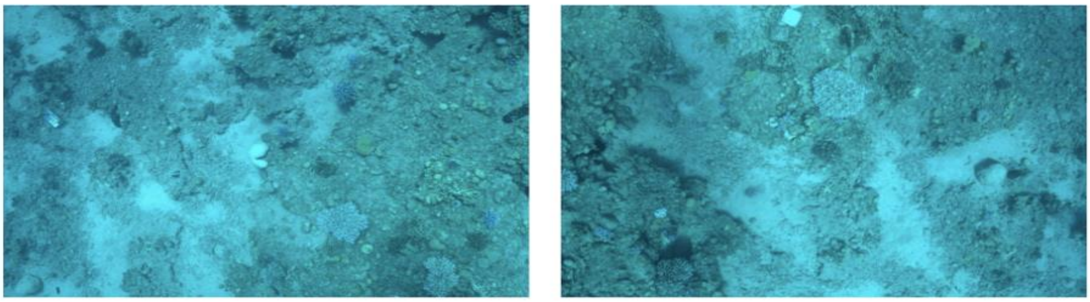


Figure 2. **Sample images from dataset D1 T_S03646 and T_S03664**

Figure 3. Sample images from dataset D3 T_S08456, T_S04858, and T_S04864

Image Processing and Restoration with the Sea-Thru Algorithm

In this process, the sampling image will be processed using the Sea-Thru algorithm from [1]. In this source code, the image to be processed must be the raw type with the ARW extension and the image depth with the TIFF extension. The first step for image restoration using the Sea-Thru algorithm is to prepare raw and tiff type images, which should be stored in the D3 folder with 2 sub-folders for raw and tiff image samples.

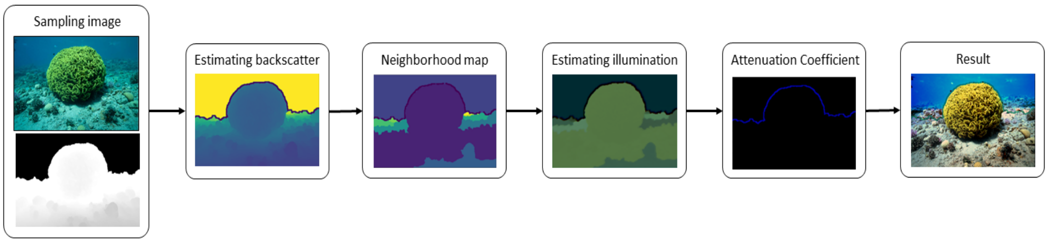


Figure 4. Restoration process in Sea-Thru Algorithm.

The first step is to estimate the backscatter. Then, construct a neighborhood map. After that, the algorithm will estimate the illumination and estimate the attenuation coefficient. Finally, the results of the restoration process using the see-thru algorithm produce good image quality.

If it is described, then the process starts with finding a point to estimate the backscatter by partitioning the image into different depth ranges and taking the darkest RGB triplet. Next, estimate the coefficients for the backscatter curve based on the value of the turning point and its depth. Constructing and refining the neighborhood map, then estimating the illumination map and estimating coefficients for the 2-term exponential describing the wideband attenuation. After that, the algorithm will find the best loss to find accurate reconstruction for the image.

The Sea-Thru algorithm used the revised equation to determine the best result of removing water from underwater images, which requires RGBD images to estimate the first backscatter from 1% darkest pixel per range per object distance, then to estimate a local illuminant map. And for the final stage is to do the finishing of the image.

Image Processing and Restoration with the Haze-Lines Algorithm

The Haze-Lines Algorithm program from Berman, Levy [2]can process raw images or RGB images, such as JPG files. The sampling images must be put in one folder before the program is executed and the result of image restoration will be saved in the result folder. Because the sampling images are raw images with an ARW extension, the image processing and restoration require a DNG file which can be obtained by using the Adobe DNG Converter.

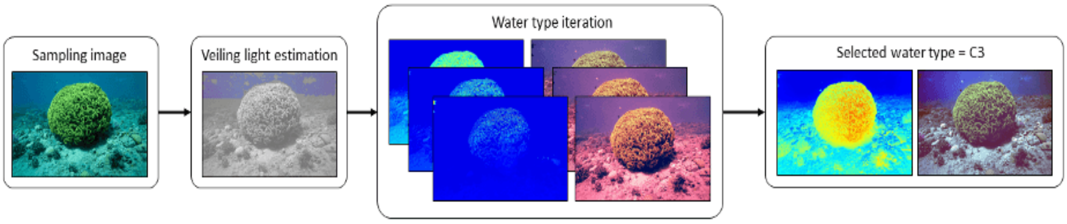


Figure 5. Restoration process in Haze-Lines Algorithm.

First, the veiling light is estimated. Then, the image will be iterated over different water types and produce the transmission estimation and color restoration. Finally, the best result was the water type selected automatically by detecting the red transmission.

The initial step of image restoration in the Haze-Lines algorithm is to prepare the raw image into a ready-to-process image in the form of an RGB image with contrast adjustment for veiling-light estimation. The veiling-light estimation aims to find the texture less region of the image by increasing contrast using Contrast-Limited Adaptive Histogram Equalization to calculate image gradients, and then find the largest connected component within the image. The result of the veiling-light estimation will be marked in a grey-level image.

To produce the best image restoration, the image will be iterated over different water types as referred from [10] with different attenuation coefficients. Every image with different water types will be restored as color images and transmission according to water types. And that transmission will be used in quality measurement to find the best type of water by calculating the red transmission average. The first transmission which is detected has a red transmission average larger by 0.1 on objects than in water, will be marked as a result.

Color Restoration Comparison

After we get the results of the image color restoration process, we can see and compare the different results of the two algorithms.

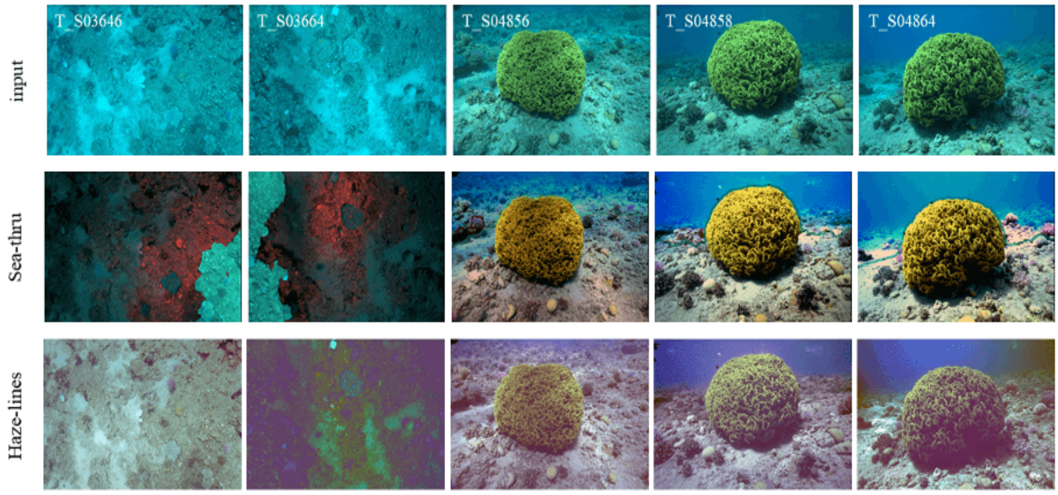


Figure 6. Raw Images and Result of Color Correction on Sea-Thru and Haze-Lines Algorithms.

The first row is the sampling images, the second row is the results of the Sea-Thru algorithm and the last row is the result of the Haze-Lines algorithm.

The image results from dataset D1, T_S03646 and T_S03664 in the second row appear to have more red color because the image has a predefined depth field and the angle of the D1 dataset is down, the algorithm can't detect the object position and object distant situation, so the algorithm can only detect the darkest spot from depth file and merge the file to be compared with default raw image. However, the D3 results in the second row, T_S08456, T_S04858, and T_S04864 are in excellent condition, with depth and color evident.

The results of the T_S03646 and T_S03664 images have significant differences because the veiling-light estimation results affect the results of the implementation of the water type, and the water type selected for the D1 result dataset is water type II and C5 respectively. While the Haze-line algorithm results from dataset D3, T_S08456, T_S04858, and T_S04864 with all angles have more noticeable magenta color, which is due to Haze-line focusing color restoration on object position within the image since the image position is further away from the object. The selected water types for dataset D3 respectively are C3, C3 and C5. Overall, the result of Haze-Lines does not turn out to be a clean image due to the influence of the type of water used in the image restoration process. But if the image results were adjusted again for contrast, the results would be cleaner.

Transmission Restoration Comparison

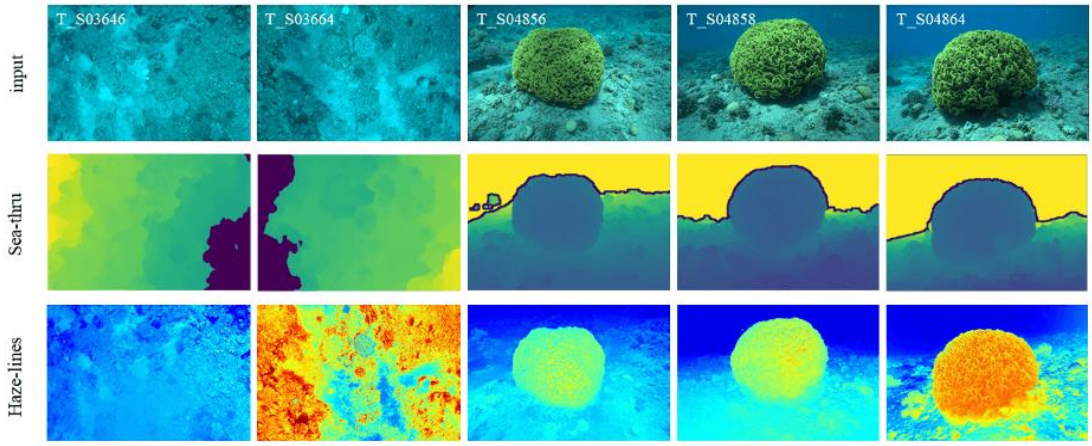


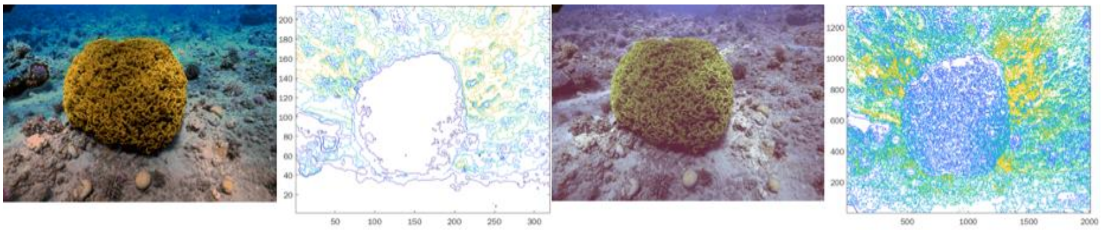
Figure 7. Depth Detection on Sea-Thru and Transmission Restoration on Haze-lines.

At this position, the application will read the range of light positions in the image where this determination is needed to be able to get the existence of the position that is obtained

Air-Light Estimation Comparison

We represent pixel intensities using a fixed set of lines emerging from a candidate air-light coordinate in RGB space given a candidate air-light coordinate. That is, we want to describe the values of pixels using an intersection point and a set of lines. An air-light at the proper RGB position will better fit the data than one in the improper place [11].

We use MatLab basic imreducehaze algorithm to get atmospheric light L using a dark channel prior. Where MatLab uses two methods *simpledcp* and *approxdcp* respectively. Both approaches use a dark channel prior, which is based on the fact that non hazy outdoor photos often contain pixels with low signal in one or more color channels.



a) Sea Thru Image, Air Light Estimation b) Haze-line Image, Air Light Estimation

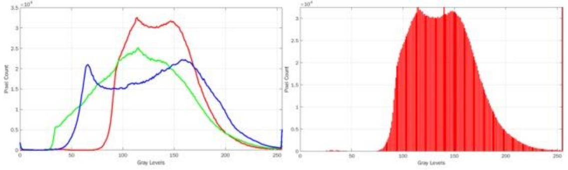
Figure 8. Air-light Estimation Comparison

The result a) is estimated light from sea thru image processing result, as you can see sea thru result responding with not too much spectrum to appear since the imreducehaze using dark channel prior, darkest side from the image will not be detected as an image prior properties.

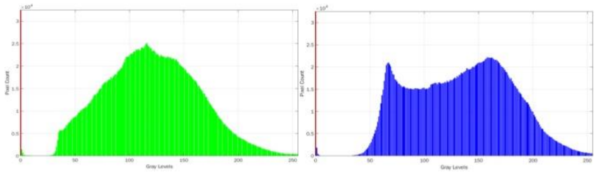
It is different from b) image result which has more path because the haze line does not calculate backscatter, which requires calculating the depth map/depth of the picture and then calculating how much contrast will show, there are numerous color components that appear in the light estimation. The three primary colors used to create the image, red, green, and blue, are represented by the color scatter.

RGB Channel by Result Comparison

We checked the histogram display to retrieve the RGB channel of each image to be tested before undertaking a more extensive comparison. The result of T_S08456 after image restoration with Haze-Lines and Sea-Thru was used as a sample image to check the depth of wavelength and color intensity. We didn't make any computations to get the plot of each color channel, this is done to reduce the minor difference between the original color and the color that will be processed.



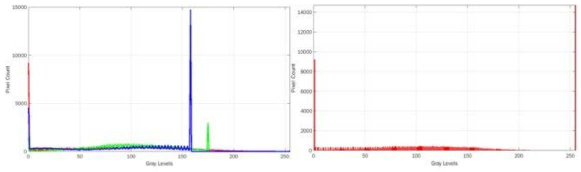
all colour wavelength intensity of red channel



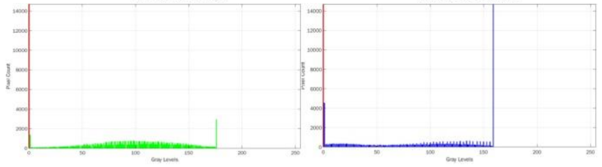
intensity of green channel intensity of blue channel

Figure 9. Haze-Lines Color Wavelength and RGB Channel

As seen in Fig. 9, the RGB channel from the Haze-Lines result appears that the highest of the red channel at the point (140, 255), the highest of the green point at (121, 255), and the highest of the blue channel at (130, 255) at the x and y axes. And to be able to get the most points out of the accomplished threshold the computation obtained is checked between *graythresh* (threshold gray color) which is multiplied by the number *255* or the last color channel of the color arrangement in the image, then converts that value into bases unit 8 bit.



all colour wavelength intensity of red channel



intensity of green channel intensity of blue channel

Figure 10. Sea-Thru Color Wavelength and RGB Channel

Since the Sea-Thru algorithm has an equal check with the depth map variable and prevents the color pattern from appearing more natural than before. So as seen in Fig. 10, the intensity of the RGB color seems to appear fewer than the result of the Haze-Lines algorithm.

Table 1.

The difference table is created by taking the average value of the three major colors and seeing how much they appear in the sample image using the MatLab built-in function.

	Difference of Mean RGB Channel		
	Red Channel	**Green Channel**	**Blue Channel**
Haze-Lines	138,1112	119,5332	132,9163
Sea-Thru	85,7495	98.7917	94,0760
Difference	52,3617	20,7415	38,8403

Conclusion

After several testing and analyzing the data, we can compare the result of the algorithms. The Sea-Thru color restoration results still can't show the true color if the angle of the image is down, while the Haze-Lines does not turn out to be a clean image due to the influence of the type of water used in the image restoration process. For the transmission restoration, it doesn't really be compared because these algorithms have their own technique so the result turns out different. In the air-light estimation using imreducehaze from MatLab, the Sea-Thru result which has been processed by estimation backscatter shows a smaller spectrum than the Haze-Lines results. And the last is a difference of mean RGB Channel of the results, it shows that RGB Channel looks stronger in the Haze-Lines result.

With that all comparison, we conclude that the two methods have their own strengths and weaknesses. The Sea-Thru algorithm which needs a depth map of the raw image for estimating backscatter can produce image results more successful in displaying object colors clearly but in this research, we found that this algorithm has a weakness when the angle of the sampling image is down. While the Haze-Lines algorithm, the result of any angles are stable but visually it seems that it needs another contrast adjustment for the final result because color contrast used in this research is more dramatic for magenta.

As a result, this comparison of underwater image processing and restoration is expected to help the development of underwater images in the next research to test other alternative algorithms for underwater image restoration to get the best results. However for now, based on this research, the Sea-Thru algorithm is better to utilize because it has a closer color coverage to the color of the original

References

1. Akkaynak, D. and T. Treibitz. *Sea-thru: A method for removing water from underwater images*. in *Conference on Computer Vision and Pattern Recognition*. 2019. DOI: https://doi.org/10.1109/CVPR.2019.00178.
2. Berman, D., et al., *Underwater single image color restoration using haze-lines and a new quantitative dataset.* IEEE transactions on pattern analysis and machine intelligence, 2020. **43**(8): p. 2822-2837 DOI: https://doi.org/10.1109/TPAMI.2020.2977624.
3. Zhang, L., et al., *A wireless communication scheme based on space-and frequency-division multiplexing using digital metasurfaces.* Nature electronics, 2021. **4**(3): p. 218-227 DOI: https://doi.org/10.1038/s41928-021-00554-4.
4. Tan, L.K., *Image file formats.* Biomed Imaging Interv J, 2006. **2**(1): p. e6 DOI: https://doi.org/10.2349/biij.2.1.e6.
5. BermanD, T., *AvidanS. Non□ localimagedehazing.* 2016IEEEConferenceonComputerVisionandPat□ ternRecognition (CVPR). IEEE, 2016 DOI: https://doi.org/10.1109/CVPR.2016.185.
6. Steiner, T., et al., *European Stroke Organization guidelines for the management of intracranial aneurysms and subarachnoid haemorrhage.* Cerebrovascular diseases, 2013. **35**(2): p. 93-112 DOI: https://doi.org/10.1159/000346087.
7. Berman, D., T. Treibitz, and S. Avidan. *Air-light estimation using haze-lines*. 2019. IEEE DOI: https://doi.org/10.1109/ICCPHOT.2017.7951489.
8. Riaz, S., et al., *Visibility Restoration Using Generalized Haze-Lines.* Inf. Technol. Control., 2021. **50**(1): p. 188-207 DOI: https://doi.org/10.5755/j01.itc.50.1.27900.
9. Dollár, P. and C.L. Zitnick. *Structured forests for fast edge detection*. 2018. DOI: https://doi.org/10.1109/ICCV.2013.231.
10. Jerlov, N.G., *Marine optics*. 1976: Elsevier.
11. Berman, N., et al., *This mine is mine! How minerals fuel conflicts in Africa.* American Economic Review, 2017. **107**(6): p. 1564-1610 DOI: https://doi.org/10.1257/aer.20150774.