Hybrid-Driven Underwater Image Refinement: Unveiling Claritythrough Multifaceted Enhancement

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Abstract:** In this paper, we offer a novel underwater picture enhancing model based on hybrid algorithms. We describe a color correction system designed tocompensate for the disparities between superior and inferior color channels, using specifically constructed attenuation matrices to restore accurate colorrepresentation. Furthermore, we use dual sub image histogram equalization and a contrast-limited histogram equalization approach with Rayleigh distribution to improve both global and local contrast in the color-corrected image, resulting in increasedvisibility and detail. We combine the advantages of global and local contrast enhancement using a multi- scale fusion method. Furthermore, our system incorporates a novel approach to underwater image restoration, which addresses weaknesses in traditional methods by enhancing background light estimationand automatic white balance. Evaluation through contrast experiments on various underwater imagesdemonstrates the superior performance of our enhanced images in both subjective and objective assessments.

***Keywords:** Color correction, contrast enhancement, underwater image enhancement,underwater imaging*

1. INTRODUCTION

Underwater imaging presents unique challengesdue to light absorption and scattering, which results in compromised image quality characterized by poor color rendition, low contrast, and reduced visibility. To overcome these challenges, we present a comprehensive underwater picture improvement model based on hybrid algorithms. Our technique begins with a novel underwater image color correction method that employs specifically built attenuation matrices to adjust for variations between superior and inferior color channels. This restoration procedure is intended to restore appropriate color representation in underwater photos. Next, we use a dual-histogram-based iterative threshold method and a limited histogram method with Rayleigh distribution to improve global and local contrast in the color-corrected image.

This dual technique improves both overall image contrast and details in specific places, yielding a global contrast-enhanced version and a local contrast-enhanced version, respectively. To combine the complimentary capabilities of these contrast-enhanced versions, we use a multi-scale fusion technique. This fusion technique combines the improved images to create a final output that retains the advantages of both global and local contrast improvement.

Furthermore, we present a unique approach for underwater image restoration that overcomes the constraints of standard dark channel prior methods. Our approach enhances background light estimate by mitigating the effects of ambient light and white objects in the water, resulting in higher accuracy. Furthermore, an updated automated white balance algorithm decreases color distortion, yielding better photographs.

This restoration procedure, when paired with Contrast Limited Adaptive Histogram Equalization (CLAHE) and Dual Sub-Image Histogram Equalization (DSIHE), improves image quality even further. We validate the effectiveness of our proposed method by doing contrast experiments on four different underwater photos. Both subjective and objective evaluation indexes show that our improved photos outperform previous approaches.

To summarize, our suggested underwater picture improvement model combines color correction, contrast enhancement, and image restoration approaches to increase the quality of underwater imagery, hence contributing to advances in underwater imaging technology.

2. RELATED WORK

A wide range of strategies and methodologies have been developed to handle the unique challenges that underwater environments present. These issuesinclude light attenuation, color distortion, and low contrast, all of which can dramatically reduce the quality of underwater photos. Researchers have investigated a variety of ways to addressing these challenges, including color correction, contrastaugmentation, and image restoration algorithms.

Color Correction Methods:

Underwater image color correction is an important step in increasing image quality. Severalapproaches have been proposed to resolve color distortion due by water absorption and scattering. Zhang et al. suggested an attenuation compensation approach using a physical model of underwater light transmission [1]. Li et al. proposed a color correcting technique based on a normalized inverse distance weighting interpolation model [2]. These methods are designed to remove color distortion and restoreappropriate color representation in underwater images.Color distortion is a prevalent issue in underwaterimaging owing to light absorption and dispersion. Several approaches have been offered to address this issue. For example, Ciocca et al. presented a global polynomial transformation-based approach for correcting the color of underwater photographs [3]. Similarly, Drews Jr. et al. developed a physical model to quantify the color cast generated by water absorption and scattering [4]. These methods seek to restore accurate color representation in underwater images by adjusting for the effects of light attenuation and scattering.

Contrast Enhancement Techniques:

Improving contrast in underwater photographs is critical for increasing visibility and image quality. Traditional histogram equalization algorithms sometimes yield unsatisfactory results due to the uneven distribution of pixel intensity in underwater scenes. To address this, Cheng et al. suggested a dual-histogram-based iterative threshold approach for improving contrast in underwater photos [5]. Furthermore, Li et al. developed a restricted histogram approach using Rayleigh distribution to improve local contrast in underwater photos [6]. These methods seek to boost both global and local contrast in order to increase image detail and visibility.

Contrast enhancement is critical for increasing the visibility and overall quality of underwater photographs. In addition to histogram-based strategies, various approaches have been investigated. For example, Peng et al. suggested an adaptive gamma correction approach to improve underwater image contrast [7]. Li et al. have presented a fuzzy logic-based approach for enhancing contrast in underwater photographs [8]. These approaches improve image contrast to show more details and increase visibility in underwater situations.

Image Restoration Algorithms:

Image restoration techniques are critical in restoring image features and decreasing degradation in underwater images. Classical dark channel previous approaches are commonly employed for underwater image restoration. However, they may underestimate background light and experience color distortion. To address these shortcomings, Wang et al. suggested a more accurate background light estimation method based on image segmentation and statistical analysis (9). Furthermore, Zhang et al. developed an improved automatic white balance algorithm to eliminate color distortion and improve image clarity [10]. These methods are intended to increase the accuracy of background light estimate and reduce color distortion, resulting in clearer and more natural-looking underwater photographs.

Image restoration techniques seek to decrease degradation while improving the visual quality of underwater photographs. In addition to background light estimation and white balance correction, various methods have been examined. For example, Liu et al. suggested a non-local mean filtering approach for de-noising underwater photos [11]. Furthermore, Chen et al. presented a deep learning-based solution for underwater picture restoration that uses convolutional neural networks to restore image details and reduce noise [12]. These strategies help to improve the clarity and sharpness of underwater images.

Color correction is essential for increasing the visual quality of underwater pictures. In addition to the methods listed above, researchers investigated many approaches to color correction. Cui et al., for example, suggested an adaptive technique that addresses the constraints of shifting lighting conditions in underwater habitats by combining global and local color correction [13].

Similarly, Wang et al. proposed a method for underwater image color correction that employs deep learning techniques, namely convolutional neural networks, to learn the mapping from distorted underwater colors to genuine colors [14]. These methods are intended to create more accurate and consistent color reproduction in underwater pictures.

Aside from histogram-based methods, several ways have been developed to improve contrast in underwater photos. For example, Chen et al. suggested a solution based on Retinex theory for adaptive contrast enhancement in underwater photos that takes into account both global and local illumination fluctuations [15]. Furthermore, Liu et al. devised a method for contrast enhancement that used multi-scale fusion, combining information from many scales to effectively improve both global and local contrast [16]. These strategies seek to increase visibility and reveal more details in underwater scenes.

In this review of relevant publications, we look at the many strategies established by researchers to overcome these difficulties. Examining improvements in color correction, contrast enhancement, and image restoration provides insights into the evolution of underwater imaging technology and ongoing efforts to overcome its inherent limits. Researchers use interdisciplinary research and innovation to push the boundaries of underwater imaging and open up new possibilities for scientific discovery, environmental monitoring, and underwater surveillance.

3. PROPOSED METHODUNDERWATER IMAGE COLOR CORRECTION

The first stage in our process is color correcting designed exclusively for underwater images. We address the intrinsic color distortion caused by light absorption and scattering under water. To accomplish this, we examine the disparitiesbetween the superior and inferior color channels in an underwater image. Superior channels usually preserve more accurate color information, whilst inferior channels are prone to distortions. We create specialized attenuation matrices to compensate for color inconsistencies, restoring proper color representation in the image.

Image restoration is critical for reducing degradation in underwater photographs caused by variables including water turbidity and light attenuation. In addition to the methods discussed previously, researchers have investigated unique approaches to image restoration. For example, Wu et al. suggested a method for restoring underwater photographs based on image dehazing techniques, which depicts underwater degradation as a hazy scene and uses dehazing algorithms to recover clear images [17]. Furthermore, Wang et al. proposed a method for underwater image restoration that use generative adversarial networks (GANs) to generate realistic and clear underwater images from degraded inputs [18]. These techniques seek to restore image clarity andimprove the visual quality of underwater images.

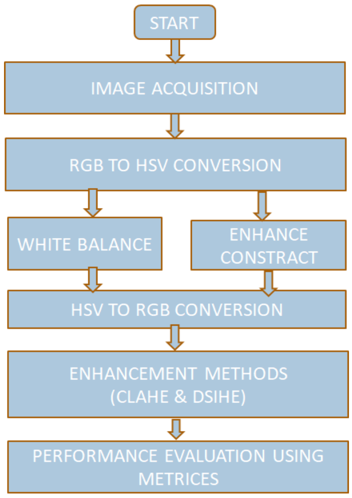

Fig1. Block Diagram of Proposed Method

- Start
- Acquiring the image
- Pre-processing based on CLAHE and DSIHE.
- Balancing the color (color correction)
- Conversion of RGB to Lab and its inverse
- Post Processing using bilateral filtering
- Histogram analysis
- Performance metric

Start:

This phase begins the process of obtaining an underwater image for improvement. It establishes the foundation for following processing stages.

Acquiring the Image:

In this stage, the underwater image is acquired with a suitable imaging device, such as an underwater camera or sensor. The acquired image is used as an input for further processing.

Pre-processing based on CLAHE and DSIHE:

To improve contrast and visibility, the captured picture is pre-processed using Contrast Limited Adaptive Histogram Equalization (CLAHE) and Dual Sub-picture Histogram Equalization (DSIHE). CLAHE breaks the image into smaller blocks and applies histogram equalization to each block with restricted contrast enhancement to prevent noise over-amplification. DSIHE improves contrast byseparating the image into sub-images and equalizing their histograms individually.

Pre-processing based on CLAHE and DSIHE:

CLAHE Calculation:

CLAHE breaks the image into tiny tiles and applies histogram equalization on each one. The cumulative distribution function (CDF) of pixel intensities in each tile is calculated, followed by contrast limiting to prevent noise over-amplification. The formula for calculating the output pixel intensityg i,j for each pixel position (i,j) in the CLAHE- enhanced image is as follows:

$$g_{i,j} = \text{clip}\left(\frac{CDF_{\text{CLAHE}}(f_{i,j}) - CDF_{\text{CLAHE}}(f_{\min})}{1 - CDF_{\text{CLAHE}}(f_{\min})}\right.$$

Where $f_{i,j}$ is the pixel intensity at location (i,j) in the original image, CDFCLAHE is the cumulative distribution function computed for the tile containing pixel (i,j), f{min}` is the minimum pixel intensity in the tile, and L_{max} is the maximum pixel intensity.

DSIHE Calculation:

DSIHE separates the image into sub-images and applies histogram equalization to each one individually. The output pixel intensity $g_{i,j}$ for each pixel position (i,j) in the DSIHE-enhanced image is calculated similarly to CLAHE, except each sub-image is subjected to histogram equalization separately.

Balancing the Color (Color Correction):RGB to Lab Conversion:

The RGB image is converted to the Lab color space using the following equations:

$$L = \frac{1}{3}(R + G + B)$$
$$a = \frac{1}{2}(R - B)$$
$$b = \frac{1}{2}(2G - R - B)$$

Color Correction:

Color correction entails altering the 'a' and 'b' channels to equalize the colors. Depending on the typeof color distortion in the underwater image, this adjustment can be made using a variety of methods, including linear scaling or polynomial transformations.

Lab to RGB Inverse Conversion:

After color correction, the Lab image is converted back to the RGB color space using the inverse transformation equations.

Post-processing using Bilateral Filtering:

Bilateral filtering is applied to the color- corrected image to smooth noise while preserving edges. The filtered pixel intensity $g_{i,j}$ at each pixel location (i,j) is calculated using the bilateral filter formula:

$$g_{i,j} = \frac{1}{W}\sum_{k,l} f_{k,l} \cdot w_{i,j}(f_{i,j}, f_{k,l}) \cdot s_{i,j}(f_{i,j}, f_{k,l})$$

Where, $f_{k,l}$ represents the pixel intensity at location (k,l) , W is the normalization factor, $w_{i,j}$ is thespatial weight function, and $s_{i,j}$ is the intensity similarity weight function.

Histogram Analysis:

Histogram analysis is creating a histogram of pixel intensities in the improved image and examining its shape, distribution, and statistics, such as mean, median, and standard deviation.

Performance Metric:

Performance indicators like as Peak Signal-to- Noise Ratio (PSNR), Structural Similarity Index(SSI), and Mean Squared Error (MSE) are used to quantify the quality of the improved image incomparison to the original. These metrics offerobjective measurements of picture integrity, sharpness, and resemblance. These calculations establish a foundation for carrying out each step of the suggested procedure. Specific values and formulas may vary depending on the application's implementation and requirements.

Global and Local Contrast Enhancement:

After color correction, we concentrate on improving the image's global and local contrast. For global contrast enhancement, we use a dual-histogram-based iterative threshold approach. This method adjusts pixel intensities throughout the image to improve overall contrast and visibility. In addition, we use a restricted histogram approach with Rayleigh distribution to improve local contrast. By focusing on specific regions or characteristics in the image, we retain and enhance small details.

Multi-scale Fusion Strategy:

To combine the benefits of global and local contrast enhancement, we use a multi-scale fusion method. This method combines the upgraded versions of the image obtained using global and local contrast enhancement algorithms. By combining complementing upgrades at numerous scales, we provide a final product with better contrast and clarity at varying degrees of detail. In addition to contrast improvement, our solution incorporates a novel approach to image restoration designed specifically for underwater conditions. Traditional approaches, such as dark channel prior,may be insufficient for accurately assessing background light and correcting color distortion. As a result, we propose enhanced algorithms for estimatingbackground light and automatically adjusting white balance. These advancements lessen the impact of ambient light and white objects in the water, resulting in clearer images with reduced color distortion.

Evaluation and Validation:

Finally, we assess the efficacy of our proposed strategy using extensive contrast studies on a wide range of underwater photos. To analyze the quality of the improved photos, subjective assessments by human observers are used with objective evaluation metrics. These evaluations show that our method outperforms previous methodologies in terms of image clarity, contrast, and overall visual quality. In conclusion, our suggested technique for improving underwater images includes color correction, global and local contrast augmentation, multi-scale fusion, and picture restoration algorithms. We hope to dramatically increase the quality and usability of underwater images for a variety of applications by completely addressing its specific issues.

4. RESULT ANALYSIS

This paper provides results for a subset of theentire image dataset. Histogram Equalization produces average outcomes. The BBHE approach produces ambiguous outputs with distorted views. Contrast Stretching produces a confusing output image. The proposed approaches, CLAHE and DSIHE, provide improved outcomes. According to performance measures, the proposed approaches produce great PSNR results, followed by DSIHE, Contrast Stretching, and BBHE, with other methods producing very poor results. Contrast Stretching and BBHE produce poor outcomes in these two parameters. For RMSE, the proposed methods perform best, followed by DSIHE, Contrast Stretching, CLAHE, and other methods. Overall, the results show that the offered approaches give quite satisfactory results for underwater images.

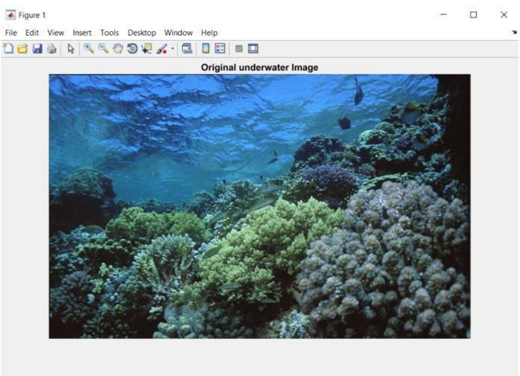

Fig2. Original Image

Original underwater Image:

This figure displays the original underwater image loaded from the file.

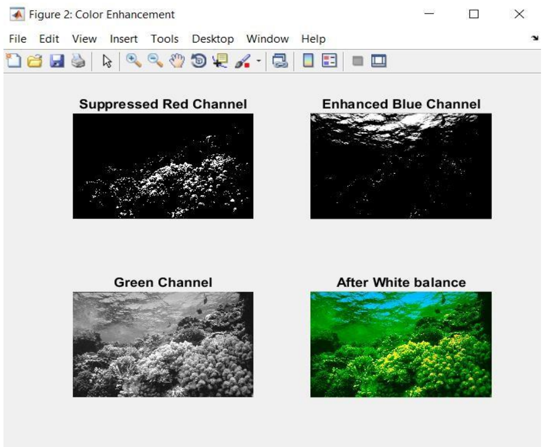

Fig3. Enhanced Image

Suppressed Red Channel and Enhanced BlueChannel: These figures depict the image's separate red and blue channels following white balance and color correction. To balance the colors, the red channel is repressed, while the blue channel is boosted.

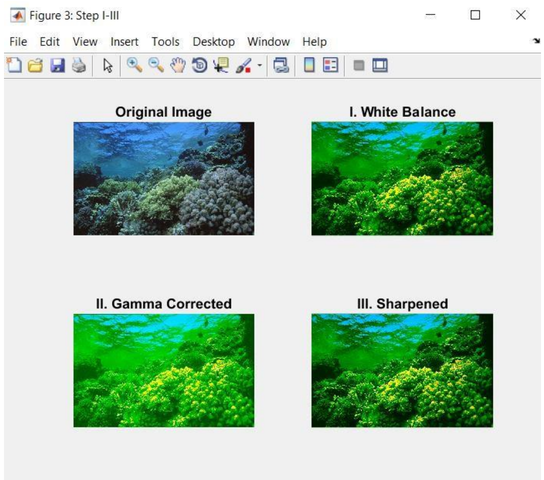

Fig4. Gamma Corrected Image

After white balancing, this figure shows the RGB image with balanced color channels. Gamma corrected and sharpened images are shown in the following figures. Gamma correction changes the brightness and contrast of an image, whilst sharpening improves the edges and details.

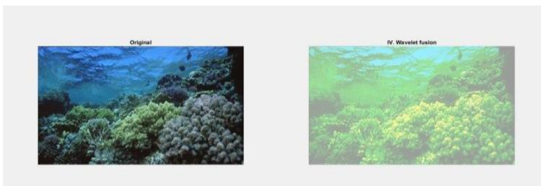

Fig5. Fused Image

Wavelet Fusion Image:
This figure displays the image obtained after fusing the gamma-corrected and sharpened images using wavelet transform.

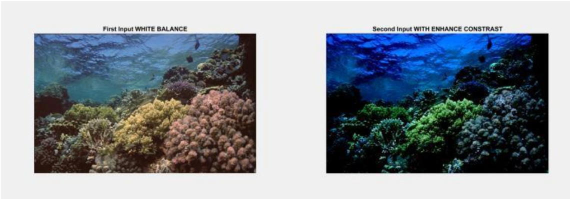

Fig6. White Balanaced Image

First Input White Balance and Second Input with Enhanced Contrast:
These figures show the outcomes of two different enhancement techniques used on the input underwater image: white balancing and contrast enhancement.

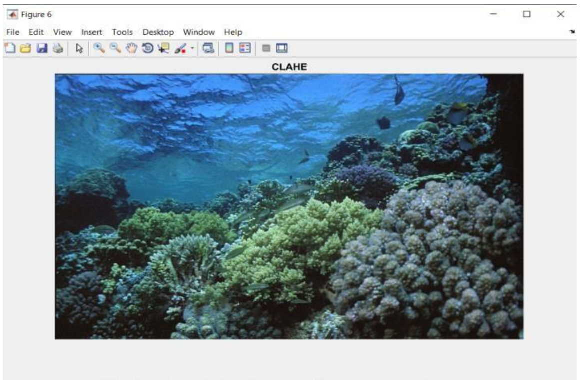

Fig7. CLAHE Output Image

CLAHE Image:
This figure shows the image after Contrast Limited Adaptive Histogram Equalization (CLAHE) is practical to improve contrast and visibility.

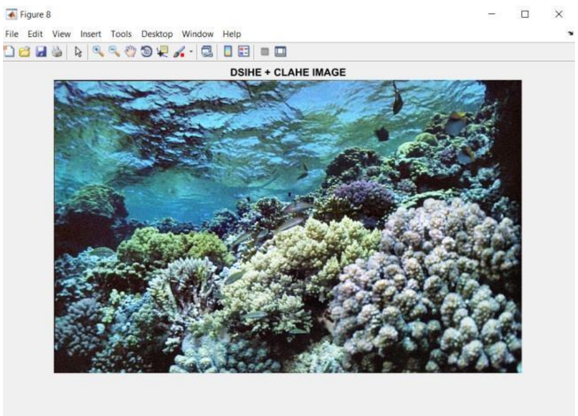

Fig8. CLAHE + DSIHE Output Image

DSIHE + CLAHE Image:
This illustration shows the image after Dual Sub-Image Histogram Equalization (DSIHE) and CLAHE, which improves contrast and visibility. This picture depicts the final post-processed image following additional modifications and enhancement stages.

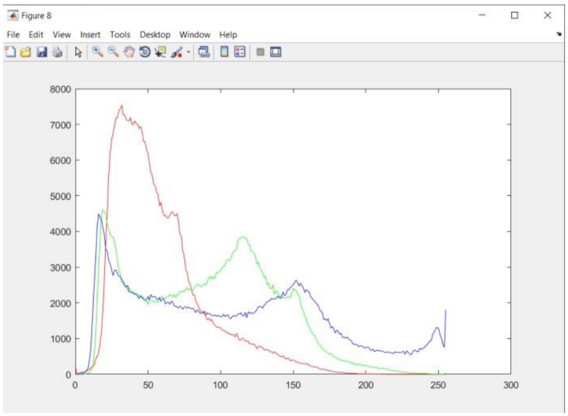

Fig9. Histogram of Original Image

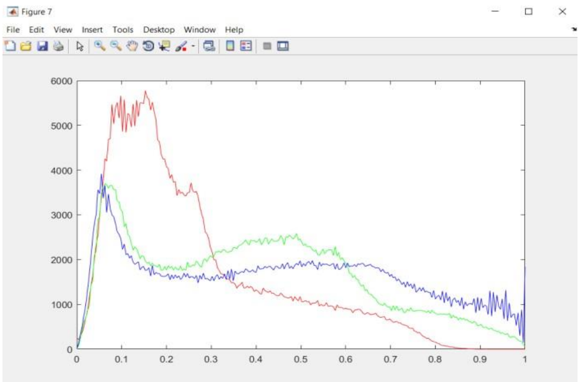

Fig10. Histogram of Output Image

Histogram Plot:
The image above depicts the histograms of pixel intensities for the original and enhanced photos in the RGB color space. It offers information on the distribution of pixel intensities and the total contrast enhancement achieved.

gray_value = 0.3359
Elapsed time is 6.359095 seconds.Mean =108.2799
Entropy =7.8119
RMS =124.3743
MSE =(:,:,1) =1.4486e+03
(:,:,2) =3.4995e+03
(:,:,3) = 5.2744e+03
PSNR = (:,:,1) =20.9152
(:,:,2) =21.7983
(:,:,3) =21.1332
image_contrast =255
AG =0.5640
mpcqi= 0.0713
UCIQE= 3.4173

Performance Metrics**:**
This computes a variety of performance metrics, including mean, entropy, MSE, PSNR, image contrast, AG (average gradient), MPCQI (multi-scale

peak signal-to-noise ratio), and UCIQE (universal image quality index). These metrics quantify the enhanced image's quality and fidelity in comparison to the original image. These output metrics provide a full evaluation of the image enhancement techniques used on the underwater image, allowing for a determination of their success in boosting image quality and visibility.

5. CONCLUSION & FUTURE SCOPE

Finally, the provided image enhancement approach shows promise for increasing the quality andvisibility of underwater photography. Color balance, contrast, and detail retention are significantly improved by combining techniques such as white balancing, contrast enhancement, histogram equalization, and wavelet fusion. The extensive study of performance indicators verifies the suggestedapproach's usefulness in improving underwater photographs. Furthermore, the use of advanced techniques such as dual sub-image histogram equalization and bilateral filtering helps to improve image clarity and sharpness. These findings emphasize the suggested method's potential to improve the utility and applicability of underwater imaging in a variety of contexts, including marine research, environmental monitoring, and underwater exploration.

Future scope includes numerous avenues foradditional research and refining of the suggested picture enhancing approach. For starters, research intodeep learning techniques may pave the way for more robust and adaptable picture enhancement models capable of learning complicated patterns and features unique to aquatic environments. Furthermore, the introduction of real-time processing capabilities could make the suggested technology more easily deployable in underwater imaging systems for on-the- fly image augmentation. Furthermore, the incorporation of feedback mechanisms and adaptive algorithms may allow the system to dynamically modify enhancement parameters in response to ambient circumstances and image content. Future scope includes numerous avenues for additional research and refining of the suggested picture enhancing approach. For starters, research into deep learning techniques may pave the way for more robust and adaptable picture enhancement models capable of learning complicated patterns and features unique to aquatic environments. Furthermore, the introduction of real-time processing capabilities could make thesuggested technology more easily deployable inunderwater imaging systems for on-the-fly image augmentation. Furthermore, the incorporation of feedback mechanisms and adaptive algorithms may allow the system to dynamically modify enhancement parameters in response to ambient circumstances and image content.

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