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Physics-Based Haze Removal and Color Correction for Enhanced Underwater Image Visibility

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Abstract: Underwater imaging environments are inherently challenging due to complex optical propagation phenomena, primarily light scattering, wavelength-dependent absorption, and suspended particulate matter. These physical effects significantly attenuate light intensity and distort spectral characteristics, resulting in degraded image quality characterized by low contrast, color imbalance, reduced sharpness, and limited visibility range. Forward and backward scattering introduce veiling light and blur fine structural details, while differential absorption of longer wavelengths (particularly red light) leads to a dominant bluish-green color cast. Consequently, underwater images exhibit diminished color fidelity, poor edge definition, and suppressed texture information, which adversely impact object detection, segmentation, and visual interpretation tasks. To mitigate these degradations, this project proposes an advanced contrast and color enhancement framework for underwater haze removal based on physics-inspired and computational image processing techniques. The proposed methodology integrates dehazing models with adaptive color restoration strategies to compensate for wavelength attenuation and scattering effects. Specifically, the system incorporates the Dark Channel Prior (DCP)–based dehazing algorithm to estimate transmission maps and ambient light components, enabling effective removal of veiling haze. In addition, color correction mechanisms such as white balance adjustment, histogram equalization, and channel-wise compensation are employed to restore chromatic consistency and recover natural color representation. The processing pipeline begins with image normalization and noise suppression, followed by transmission estimation and scene radiance recovery. Contrast enhancement techniques, including adaptive histogram equalization (AHE) or contrast-limited adaptive histogram equalization (CLAHE), are applied to improve local contrast without amplifying noise. To further refine visual clarity, edge-preserving filtering methods such as guided filtering are utilized to smooth transmission maps while maintaining structural boundaries. The combined approach ensures enhanced visibility, improved depth perception, and restoration of object features that are otherwise obscured by turbidity. The developed system is implemented in MATLAB, leveraging its image processing toolbox for algorithm prototyping, matrix-based computation, and visualization. Performance evaluation is conducted on diverse underwater datasets captured under varying turbidity levels and lighting conditions. Quantitative assessment metrics such as Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), Underwater Image Quality Measure (UIQM), and contrast gain are used to validate enhancement performance. Experimental results demonstrate improved color balance, enhanced edge sharpness, and significant visibility restoration compared to conventional enhancement techniques. By improving visual interpretability and structural detail recovery, the proposed method supports applications in marine exploration, underwater robotics, coral reef monitoring, archaeological surveys, autonomous underwater vehicle (AUV) navigation, and environmental research. The framework provides a computationally efficient and adaptable solution suitable for both offline analysis and potential real-time underwater imaging systems.

Keywords: Physics-Based, Haze Removal, Color Correction, Underwater, Image Visibility, Image processing, MATLAB.

I. INTRODUCTION

Underwater imaging plays a crucial role in marine biology, oceanographic research, underwater robotics, archaeological exploration, and environmental monitoring. However, capturing high-quality underwater images remains a significant challenge due to complex optical degradation phenomena. Light propagation in water is affected by wavelength-dependent absorption and scattering caused by suspended particles and dissolved organic matter. These effects introduce haze, reduce

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contrast, distort color balance, and significantly degrade image clarity. The rapid attenuation of red wavelengths results in a dominant bluish-green tint, while backscattering produces veiling light that reduces scene visibility.

To address these issues, advanced computational techniques are required to restore scene radiance and improve perceptual quality. This research proposes a physics-based haze removal and color correction framework that combines transmission map estimation, dark channel prior (DCP)-based dehazing, and adaptive contrast enhancement techniques. The objective is to recover natural colors, improve structural visibility, and enhance image interpretability for underwater applications.

II. REVIEW OF LITERATURE

Early underwater image enhancement techniques primarily relied on global histogram equalization and white balance correction to improve brightness and contrast. However, these approaches often failed to compensate for depth-dependent color attenuation and non-uniform haze distribution.

He et al. (2011) introduced the Dark Channel Prior (DCP) for single-image dehazing in atmospheric conditions, which later inspired adaptations for underwater imaging. Chiang and Chen (2012) proposed wavelength compensation and image dehazing (WCID) to address color cast and scattering simultaneously. Ancuti et al. (2018) developed a fusion-based underwater image enhancement approach that combines multiple inputs to improve visual quality.

More recently, deep learning-based models such as convolutional neural networks (CNNs) and generative adversarial networks (GANs) have been applied to underwater image restoration. Although these approaches demonstrate promising results, they require large annotated datasets and high computational resources. In contrast, physics-based methods remain attractive due to their interpretability, lower computational complexity, and suitability for real-time deployment. The proposed work builds upon the dark channel prior model while integrating adaptive color and contrast restoration mechanisms for improved robustness.

III. SYSTEM METHODOLOGY

The proposed system follows a multi-stage image processing pipeline implemented in MATLAB. The methodology includes preprocessing, transmission estimation, scene radiance recovery, color correction, and contrast enhancement.

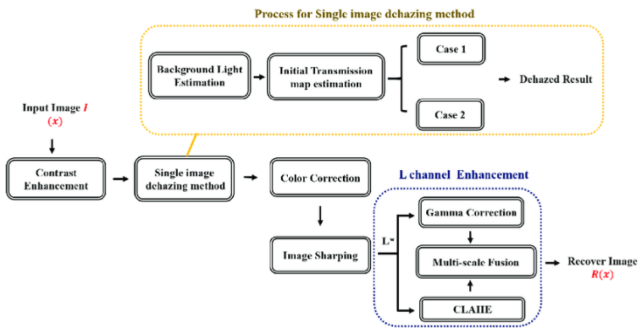

Figure 1: Block diagram of proposed technique

Initially, input underwater images undergo noise reduction and normalization to suppress random artifacts. The dark channel prior is then applied to estimate the transmission map by identifying minimum intensity values across local patches. This step helps approximate the haze thickness and ambient light components.

Using the estimated transmission map, scene radiance recovery is performed to reconstruct the haze-free image. A guided filtering technique is incorporated to refine the transmission map while preserving edge structures.

Block Diagram Description

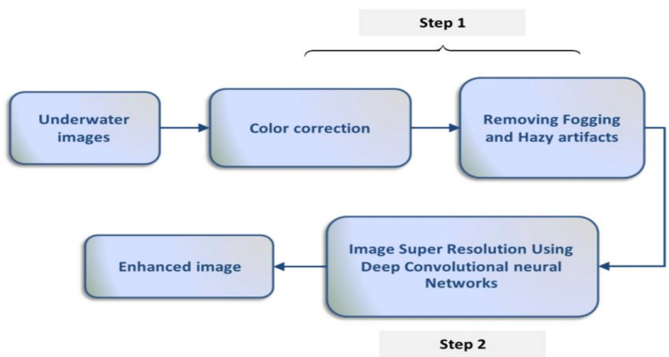

Figure 2: Color correction

Subsequently, adaptive color correction is applied to compensate for wavelength attenuation, particularly restoring red channel intensity. White balance adjustment and channel-wise

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gain compensation are employed to reduce bluish-green dominance. The proposed underwater image enhancement system follows a sequential multi-stage processing architecture designed to progressively restore degraded underwater images. The overall block diagram consists of the following primary modules:

1. Input Image Acquisition

The system begins with the acquisition of a degraded underwater image. The captured image typically contains haze, reduced contrast, color imbalance, and scattering artifacts caused by underwater optical propagation.

2. Preprocessing Module

This stage performs image normalization and noise suppression. Median or Gaussian filtering may be applied to reduce random noise while preserving edge information. The image is converted into an appropriate color space (e.g., RGB) for further processing.

3. Dark Channel Estimation

The dark channel prior (DCP) is computed by identifying the minimum intensity value within local patches across RGB channels. This step estimates haze density and provides the foundation for transmission map calculation.

4. Transmission Map Estimation

Using the dark channel, the transmission map is estimated to determine the portion of light that reaches the camera without scattering. A guided filter is applied to refine the transmission map and preserve structural edges.

5. Scene Radiance Recovery

Based on the atmospheric scattering model adapted for underwater conditions, the haze-free scene radiance is reconstructed using the estimated transmission map and ambient light value.

6. Color Correction Module

Channel-wise compensation and white balance adjustment are performed to counteract wavelength-dependent absorption, particularly restoring red channel attenuation.

7. Contrast Enhancement Module

Contrast-Limited Adaptive Histogram Equalization (CLAHE) enhances local contrast and improves perceptual sharpness without amplifying noise.

8. Output Enhanced Image

The final output is a visually enhanced underwater image with improved clarity, color fidelity, and structural detail. This modular architecture ensures computational efficiency, scalability, and compatibility with real-time marine imaging applications.

Mathematical Modeling

Underwater image degradation can be described using a modified atmospheric scattering model. The observed underwater image *I(x)* at pixel location *x* is modeled as:

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

where:

I(x) = observed degraded image
J(x) = scene radiance (true image)
t(x) = transmission map
A = global ambient light
x = pixel location

1. Transmission Map

The transmission map represents the fraction of scene radiance that reaches the camera without scattering:

$$t(x) = e^{-\beta d(x)}$$

where:

β = medium attenuation coefficient
d(x) = scene depth

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$$t(x) = 1 - \omega \min_{y\in\Omega(x)} \left(\min_{c\in\{r,g,b\}} \frac{I^c(y)}{A^c} \right)$$

In practical implementation using the Dark Channel Prior:

where:

Ω(x) = local patch centered at pixel
c = color channel (R, G, B)
ω∈[0,1] = haze retention parameter (typically 0.95)

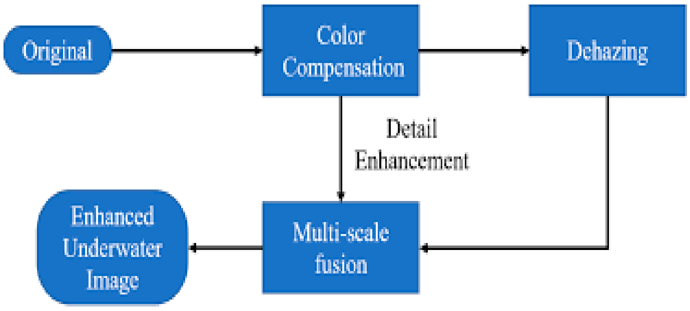

Figure 3: Color compensation

2. Scene Radiance Recovery

Once the transmission map is estimated, the haze-free image is reconstructed as:

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

3. Color Compensation Model

Underwater environments cause wavelength-dependent attenuation:

$$I_c(x) = J_c(x) \cdot e^{-\beta_c d(x)}$$

4. Contrast Enhancement (CLAHE)

For local contrast enhancement, histogram equalization is applied to image tiles. The transformation function is defined as:

$$g(i) = \frac{CDF(i) - CDF_{min}}{(M \times N) - CDF_{min}} \times (L - 1)$$

Finally, contrast enhancement techniques such as Contrast-Limited Adaptive Histogram Equalization (CLAHE) are applied to improve local contrast without amplifying noise. The enhanced output image exhibits improved clarity, color balance, and structural detail recovery.

Performance evaluation is conducted using quantitative metrics including Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Underwater Image Quality Measure (UIQM).

IV. RESULTS AND DISCUSSIONS

The proposed method was tested on multiple underwater images captured under varying turbidity and lighting conditions. Experimental results demonstrate significant improvement in visibility, edge sharpness, and color restoration compared to conventional histogram equalization techniques.

Quantitative analysis shows increased PSNR and SSIM values, indicating better structural preservation and reduced distortion. The UIQM metric confirms enhancement in colorfulness, sharpness, and contrast. The dark channel-based transmission estimation effectively removes haze while maintaining depth consistency.

Visual inspection reveals that the proposed system restores natural color tones and improves object boundary definition, making marine objects such as corals, rocks, and underwater equipment more distinguishable. Additionally, the algorithm demonstrates computational efficiency suitable for near real-time applications.

While the method performs effectively in moderate turbidity conditions, extremely dense scattering environments may require more advanced depth estimation or learning-based approaches.

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V. CONCLUSION AND FUTURE SCOPE

This research presents a physics-based underwater image enhancement framework integrating dark channel prior dehazing, color correction, and adaptive contrast enhancement. The proposed system effectively mitigates scattering-induced haze and wavelength-dependent absorption, resulting in improved visibility and natural color restoration. Implementation in MATLAB demonstrates practical feasibility and computational efficiency.

Future research may explore hybrid approaches that combine physics-based models with deep learning architectures for enhanced robustness. Incorporating depth estimation models and polarization-based imaging could further improve restoration accuracy. Real-time implementation on embedded systems or integration with autonomous underwater vehicles (AUVs) represents another promising direction. Additionally, dataset-driven benchmarking using standardized underwater image datasets will strengthen performance validation.

REFERENCES

[1] K. He, J. Sun, and X. Tang, “Single Image Haze Removal Using Dark Channel Prior,” IEEE Transactions on Pattern Analysis and Machine Intelligence, 2011.
[2] J. Y. Chiang and Y. C. Chen, “Underwater Image Enhancement by Wavelength Compensation and Dehazing,” IEEE Transactions on Image Processing, 2012.
[3] C. Ancuti, C. O. Ancuti, T. Haber, and P. Bekaert, “Enhancing Underwater Images and Videos by Fusion,” IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2012.
[4] D. Berman, T. Treibitz, and S. Avidan, “Diving into Haze-Lines: Color Restoration of Underwater Images,” British Machine Vision Conference (BMVC), 2017.
[5] S. Drews, E. Nascimento, S. Botelho, and M. Campos, “Transmission Estimation in Underwater Single Images,” IEEE International Conference on Computer Vision Workshops, 2013.
[6] T. Treibitz and Y. Schechner, “Turbid Scene Enhancement Using Multi-Directional Illumination Fusion,” IEEE Transactions on Image Processing, 2012.
[7] C. O. Ancuti, C. Ancuti, and P. Bekaert, “Color Balance and Fusion for Underwater Image Enhancement,” IEEE Transactions on Image Processing, vol. 27, no. 1, pp. 379–393, 2018.
[8] D. Akkaynak and T. Treibitz, “A Revised Underwater Image Formation Model,” IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2018.
[9] T. Treibitz and Y. Y. Schechner, “Active Polarization Descattering,” IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 31, no. 3, pp. 385–399, 2009.
[10] R. Fattal, “Single Image Dehazing,” ACM Transactions on Graphics, vol. 27, no. 3, 2008.
[11] S. Emberton, L. Chittka, and A. Cavallaro, “Underwater Image and Video Dehazing with a Physical Model,” IEEE Conference on Computer Vision and Pattern Recognition Workshops, 2015.
[12] P. Drews-Jr, E. Nascimento, S. Botelho, and M. Campos, “Underwater Depth Estimation and Image Restoration Based on Single Images,” IEEE Computer Graphics and Applications, vol. 36, no. 2, pp. 24–35, 2016.
[13] Y. Li, J. Guo, H. Cong, S. Pang, and J. Wang, “Underwater Image Enhancement by Dehazing with Minimum Information Loss and Histogram Distribution Prior,” IEEE Transactions on Image Processing, vol. 25, no. 12, pp. 5664–5677, 2016.
[14] C. Li, S. Anwar, and F. Porikli, “Underwater Scene Prior Inspired Deep Underwater Image and Video Enhancement,” Pattern Recognition, vol. 98, 2020.
[15] X. Fu, P. Zhuang, Y. Huang, X. Liao, X. Zhang, and X. Ding, “A Retinex-Based Enhancing Approach for Single Underwater Image,” IEEE International Conference on Image Processing (ICIP), 2014.
[16] M. Chiang and Y. Chen, “Underwater Image Enhancement Using Adaptive Compensation and Dehazing Model,” IEEE Journal of Oceanic Engineering, vol. 42, no. 4, pp. 911–925, 2017.
[17] S. Wang, Y. Zhang, D. Liu, and B. Guo, “Underwater Image Enhancement via Medium Transmission-Guided Multi-Color Space Embedding,” IEEE Transactions on Image Processing, 2019.
[18] J. Peng and C. Cosman, “Underwater Image Restoration Based on Image Blurriness and Light Absorption,” IEEE Transactions on Image Processing, vol. 26, no. 4, pp. 1579–1594, 2017.

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