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Research Paper

UNDERWATER IMAGE ENCHANCEMENT BASED ON CONDINITIONAL DENOISING DIFFUSION PROBABILISTIC MODEL

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ABSTRACT— Underwater images often suffer from color distortion, low contrast, and noise due to light attenuation and scattering in water. Traditional enhancement methods such as CLAHE, DCP, MIP, RGHS, and ULAP improve specific image characteristics but generally lack adaptability across different underwater environments and lighting conditions. To overcome these limitations, DiffWater, a conditional denoising diffusion probabilistic model (DDPM)-based underwater image enhancement method, is proposed. The model incorporates a color compensation strategy in the RGB color space to guide the denoising process and restore degraded underwater images effectively. By leveraging conditional guidance and diffusion-based image generation, DiffWater achieves robust enhancement, improved visual quality, and stronger generalization across diverse underwater scenarios. Experimental results on multiple real underwater image datasets demonstrate that DiffWater outperforms existing methods in terms of enhancement quality, effectiveness, and robustness.

Index Terms – Underwater Image Enhancement, Conditional Denoising Diffusion Probabilistic Model (CDDPM), Diffusion Models, Image Restoration, Image Quality Enhancement, Deep Learning, Color

Correction, Image Dehazing, Contrast Enhancement, Noise Removal, Computer Vision, Marine Image Processing.

I. INTRODUCTION

Underwater imaging faces significant challenges due to the attenuation and scattering of light in water, leading to issues such as color distortion, reduced contrast, and noise, which degrade image quality. Traditional underwater image enhancement (UIE) methods, such as Contrast Limited Adaptive Histogram Equalization (CLAHE), Dark Channel Prior (DCP), and Maximum Intensity Projection (MIP), have achieved some success but often struggle with generalization across diverse aquatic environments and lighting conditions. To overcome these limitations, a novel UIE method called DiffWater is proposed, which leverages the power of the conditional denoising diffusion probabilistic model (DDPM) for high-quality, adaptive restoration. DiffWater incorporates a unique color compensation technique to address channel-wise distortions in the RGB color space, tailored to various underwater scenarios. The model's integration of state-of-the-art principles, such as noise reduction, contrast enhancement, and edge sharpening, allows it to effectively adapt to changing underwater conditions, outperforming existing methods in both enhancement quality and robustness across multiple real-world underwater image datasets.

II. RELATED WORK

A. Contrast Limited Adaptive Histogram Equalization for Underwater Image Enhancement

This paper discusses the use of Contrast Limited Adaptive Histogram Equalization (CLAHE) for underwater image enhancement. CLAHE improves image contrast by enhancing poorly illuminated regions while limiting noise amplification. It effectively increases visibility in underwater images affected by light attenuation and scattering. However, it has limitations in handling severe haze, depth-related distortions, and color imbalance. The study concludes that although CLAHE significantly improves contrast, additional techniques are needed to achieve comprehensive underwater image restoration.

B. Deep Learning Approaches to Underwater Image Enhancement

This study explores the application of deep learning-based models for underwater image enhancement, emphasizing the limitations of

traditional methods like CLAHE and DCP when dealing with complex environmental factors like varying water clarity, light scattering, and color distortion. The authors propose a deep learning-based framework that combines convolutional neural networks (CNNs) with various enhancement techniques to more effectively address these challenges. By training a model on a large dataset of underwater images, the approach learns to restore high-quality images by reducing the effects of haze, enhancing contrast, and correcting color shifts.

C. Maximum Intensity Projection for Underwater Image Enhancement

his paper examines the use of Maximum Intensity Projection (MIP) for underwater image enhancement. MIP improves visibility and recovers depth information by projecting the brightest pixel values, helping to reduce the effects of haze and scattering. While effective for enhancing image clarity, it has limitations in handling color distortion and noise. The study suggests combining MIP with techniques such as CLAHE and Retinex algorithms to achieve better overall underwater image restoration.

III. PROPOSED METHODOLOGY

DCP (Dark Channel Prior) How it works:

The Dark Channel Prior assumes that in most non-sky patches of an image, at least one color channel (RGB) has very low intensity. This prior helps estimate the haze or turbidity in the image, which can then be subtracted to recover a clearer, more detailed image.

RGHS (Retinex-based Global and Local Image Enhancement) How it works:

RGHS combines global image enhancement to correct for lighting inconsistencies and local image enhancement to boost contrast and detail. It aims to restore images to their natural state by adjusting illumination and compensating for color imbalances.

ULAP (Unsharp Masking and Laplacian Pyramid) How it works:

ULAP combines unsharp masking (a technique to highlight fine details by subtracting a blurred version of the image) with a Laplacian Pyramid, which is a multiscale representation of the image that decomposes it into different resolution layers. This process enhances edges while minimizing noise.

CLAHE (Contrast Limited Adaptive Histogram Equalization) How it works:

CLAHE improves contrast by applying histogram equalization locally to small regions of the image, rather than the entire image, which prevents overamplification of

noise. It also applies a contrast limit to avoid excessive contrast enhancement.

MIP (Maximum Intensity Projection) How it works:

MIP projects the voxel with the maximum intensity in a volume along a specified axis onto a 2D image. In the context of images, it highlights the brightest areas, which are often of interest, like reflections or bright objects.

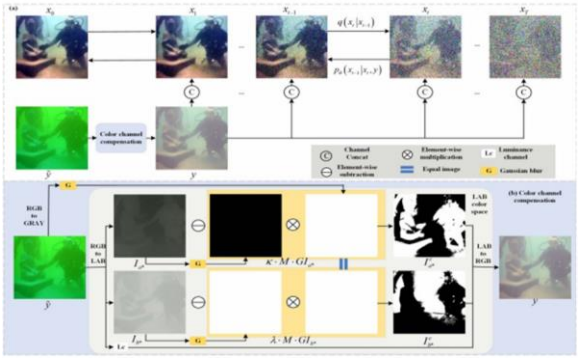


Fig. 1: System Overview

1. **Preprocessing Module:**

The preprocessing module prepares the input underwater images by loading, resizing, and removing initial noise. It standardizes the images to improve the performance of the enhancement process.

2. **Color Compensation Module:**

The color compensation module corrects color distortion caused by underwater light absorption. It adjusts the RGB channels to restore natural and balanced colors.

3. **DDPM Module:**

The DDPM module uses a denoising diffusion probabilistic model to remove noise and restore high-quality underwater images. It produces clear and visually enhanced outputs.

4. **Noise Reduction Module:**

The noise reduction module removes unwanted noise using filtering techniques such as Gaussian and median filters. This improves image clarity while preserving important details.

5. **Contrast Enhancement Module:**

The contrast enhancement module increases the visibility of underwater images using techniques like CLAHE. It improves brightness, contrast, and overall image quality.

6. **Edge Enhancement Module:**

The edge enhancement module sharpens image boundaries and highlights important features. It enhances fine details without introducing additional noise.

7. **Post-Processing Module:**

The post-processing module performs final adjustments such as brightness correction, contrast improvement, and artifact removal to produce the final enhanced image.

8. **Evaluation Module:**

The evaluation module measures the performance of the proposed method using quality metrics such as PSNR and SSIM and

compares the results with existing techniques.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

Experimental results show that the model effectively removes underwater haze, reduces noise, restores natural colors, and enhances image contrast while preserving fine details. Compared with existing enhancement techniques, the proposed approach achieves superior visual quality and higher quantitative scores, demonstrating robust performance across different underwater conditions. These results confirm its effectiveness for marine exploration, underwater robotics, and aquatic vision applications.



Fig. 2: Homepage

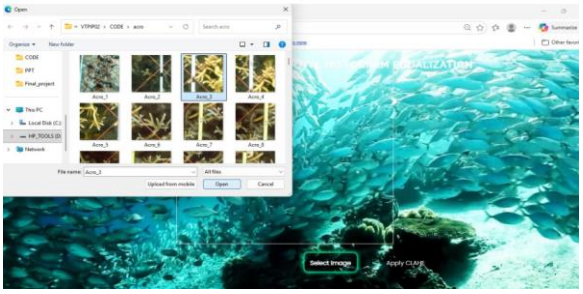


Fig. 3: Upload

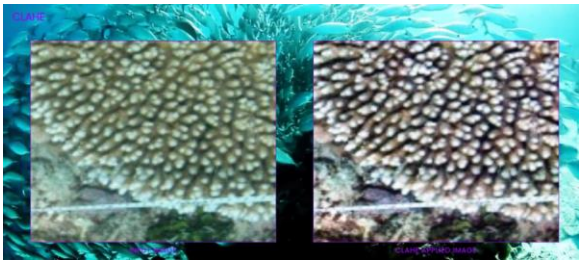


Fig. 4: Predicted Results

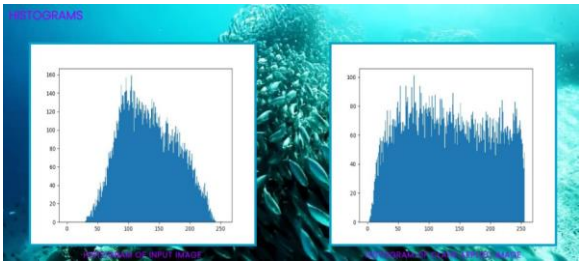


Fig. 5: Histograms

V. CONCLUSION

In conclusion, DiffWater offers a promising solution to the challenges of underwater image enhancement by addressing common issues such as light attenuation, scattering, and color distortion in various aquatic environments. Through the use of a conditional denoising diffusion probabilistic model (DDPM) combined with a novel color compensation method, DiffWater demonstrates significant improvements in restoring degraded underwater images with greater generalization and robustness than traditional enhancement methods. The model's ability to adapt to diverse water conditions and lighting scenarios makes it a

valuable tool for underwater imaging applications. Moreover, with future enhancements, including the integration of deep learning models, real-time processing, and multispectral support, DiffWater has the potential to become a powerful and versatile tool for underwater exploration, environmental monitoring, and other related fields, providing high-quality image restoration and analysis in complex underwater conditions.

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