Single Underwater Image Restoration Using Variational Framework Guided by Imaging Model with Noise

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Abstract - Underwater images often suffer from severe degradation due to light absorption, scattering, and noise, resulting in low contrast, color distortion, and reduced visibility. To address these challenges, this paper presents a robust image restoration framework based on a variational model guided by the underwater imaging process. The method begins with accurate background light estimation using dark channel prior techniques, followed by transmission map computation and refinement to correct illumination and haze effects.

Further enhancement is achieved by integrating Bidimensional Empirical Mode Decomposition (BEMD) and unsharp masking to improve structural details and edge sharpness while reducing noise. The variational framework formulates image restoration as an optimization problem that balances data fidelity and regularization, ensuring both clarity and smoothness in the output image.

Experimental results demonstrate significant improvement in Peak Signal-to-Noise Ratio (PSNR) and visual quality, proving the effectiveness of the proposed approach for underwater image enhancement.

Key Words: Underwater Image Restoration, Variational Framework, BEMD, Transmission Map, Background Light Estimation, Image Enhancement, Noise Reduction, PSNR

1. INTRODUCTION

Underwater imaging is widely used in marine research, environmental monitoring, and underwater exploration. However, images captured underwater are highly degraded due to light absorption, scattering, and wavelength attenuation, leading to poor contrast and color distortion.

Traditional image enhancement techniques fail to effectively restore both structural details and color balance simultaneously. Variational framework-based approaches provide a better solution by modeling the physical imaging process and reconstructing the degraded image through optimization. However, these methods still face limitations such as dependency on accurate initial estimates and lack of detail enhancement**.**

To overcome these issues, this paper proposes an improved underwater image restoration framework that integrates variational modeling with BEMD and image sharpening techniques to enhance image clarity and performance.

2. LITERATURE SURVEY

Various techniques have been developed for underwater image restoration to handle issues like scattering, absorption, and noise. Basic methods such as histogram equalization and white balancing improve contrast but do not effectively restore true color and depth information [1].

Model-based approaches, including dark channel prior and haze-line methods, estimate transmission maps and background light for better scene recovery. Although these methods improve visibility, they may produce errors under complex underwater conditions [2].

Recent techniques focus on adaptive color correction and hybrid frameworks to enhance image quality. Variational and optimization-based methods further improve restoration by balancing noise reduction and detail preservation. However, challenges such as computational complexity and noise amplification still remain [3].

3. EXISTING SYSTEM

The existing underwater image restoration approach is based on the physical imaging model, which includes background light estimation, transmission map computation, and image reconstruction. Initially, the background light is estimated by selecting regions with high intensity and low variation. Then, the transmission map is calculated to model the amount of light reaching the camera, followed by refinement to reduce noise effects [1].

A variational framework is applied to restore the image by optimizing an energy function that balances data fidelity and smoothness. While this method improves contrast and visibility, it suffers from limitations such as noise amplification, inaccurate estimation in complex environments, and lack of effective detail enhancement [2].

4. PROPOSED SYSTEM

The proposed method presents an advanced underwater image restoration framework based on a variational model guided by the physical imaging process and noise characteristics. The overall system follows a multi-stage pipeline to effectively handle degradation caused by scattering, absorption, and noise.

First, the input underwater image undergoes background light estimation, where the image is divided into multiple regions and the most suitable region is selected based on intensity, smoothness, and color consistency. This ensures accurate estimation of ambient light, which is essential for proper restoration. Next, the transmission map is computed to model the amount of light reaching the camera. This map is further refined using filtering techniques to remove noise and improve edge preservation.

After obtaining the transmission map, a variational framework is applied to reconstruct the latent clear image. The restoration process is formulated as an optimization problem that minimizes an energy function consisting of two main components: a data fidelity term to maintain similarity with the observed image and a regularization term to enforce smoothness and reduce noise. This helps in achieving a balance between detail preservation and noise suppression.

To further enhance performance, Bidimensional Empirical Mode Decomposition (BEMD) is incorporated. This technique decomposes the image into multiple intrinsic mode functions, allowing separation of noise components and fine structural details. By selectively processing these components, the method effectively removes noise while preserving important features.

Finally, unsharp masking is applied to enhance edges and improve image sharpness. This step increases the clarity of object boundaries and fine details, resulting in a visually improved image. The proposed framework is also computationally efficient and adaptable to varying underwater conditions such as depth changes, turbidity, and non-uniform illumination. It ensures robust performance against different types of noise while preserving natural color appearance and avoiding over-enhancement.

Overall, the proposed method provides significant improvements in contrast, color correction, and noise reduction. It achieves better performance in terms of Peak Signal-to-Noise Ratio (PSNR), Mean Square Error (MSE), and visual quality, making it suitable for real-world underwater imaging applications such as marine exploration, surveillance, and autonomous underwater systems.

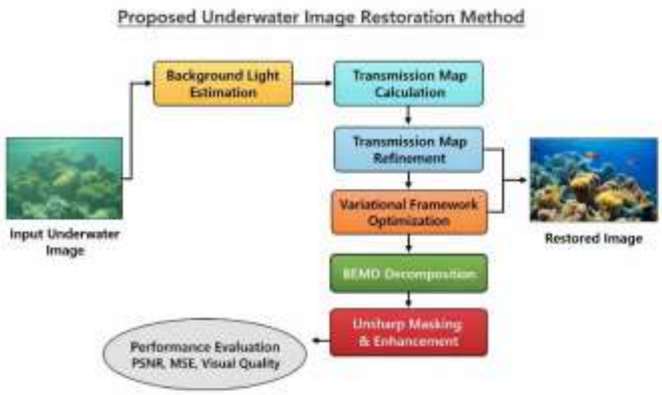

Fig 1. Block Diagram of Proposed Method

The proposed method diagram represents the step-by-step process for restoring underwater images affected by noise, low contrast, and color distortion. The process begins with the input underwater image, which typically suffers from visibility issues due to light absorption and scattering in water.

The first stage is background light estimation, where the system identifies the ambient light present in the underwater environment. This step is important because incorrect estimation can lead to poor color correction. After that, the transmission map estimation is performed to determine how much light is transmitted from the scene to the camera. This map helps in understanding the level of degradation in different regions of the image.

Next, the transmission map is improved using refinement techniques to remove noise and preserve edges. The refined data is then passed into the variational framework optimization block, which is the core part of the system. In this stage, an energy function is minimized to recover the clear image while balancing noise removal and detail preservation.

Further enhancement is done using BEMD (Bidimensional Empirical Mode Decomposition), which separates noise components from useful image details. This allows better restoration without losing important features. Then, unsharp masking is applied to sharpen the image and enhance edges, improving visual clarity.

Finally, the output is the restored image, which shows improved contrast, better color balance, and reduced noise. The performance of the method is evaluated using metrics such as PSNR, MSE, and visual quality, confirming the effectiveness of the proposed approach.

5. RESULTS

Fig 2. Input image

This figure represents the original underwater image affected by scattering, absorption, low contrast, and color distortion. It serves as the baseline for evaluating the performance of the proposed restoration method.

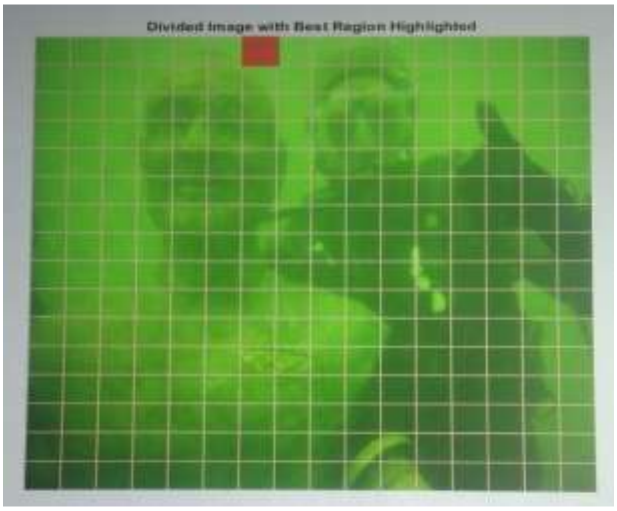

Fig 3. Divide Image with Best Region Highlight

The input image is divided into multiple regions, and the optimal region is highlighted based on intensity and smoothness. This step is used for accurate background light estimation**.**

Fig 4. I/p Image with Best Region Highlight

This figure shows the selected best region mapped onto the original image. It helps visualize the region used for estimating ambient light for further processing.

Fig 5. Corrected Transmission Map

The transmission map is initially estimated to represent light propagation through water. This figure shows a refined version where noise is partially reduced.

Fig 6. Corrected Transmission Map

Further refinement is applied to improve edge preservation and reduce distortions, resulting in a more accurate representation of scene depth.

Fig 7. Corrected Transmission Map

This figure presents the final corrected transmission map with enhanced smoothness and better structural consistency.

Fig 8. Combined Initial Transmission Map

Multiple transmission maps are combined to produce a more stable and reliable estimation, improving the overall restoration process.

Fig 9. Restored Image

This image shows the output after applying the variational framework. It demonstrates improved contrast, visibility, and color correction compared to the input image.

Fig 10. BEMD Enhanced

The image after applying Bidimensional Empirical Mode Decomposition (BEMD) shows enhanced structural details and reduced noise while preserving important features.

Fig 11. Un sharp Mask

The final output image after unsharp masking highlights sharper edges and improved clarity, making the image visually more appealing and detailed.

CONCLUSION

This paper presents an advanced underwater image restoration technique based on a variational framework guided by an imaging model with noise. By integrating transmission map refinement, BEMD decomposition, and unsharp masking, the proposed method significantly improves image quality.

The results demonstrate enhanced PSNR, reduced noise, and improved visual clarity. The method is computationally efficient and suitable for practical applications in underwater imaging. Future work can focus on real-time implementation and integration with deep learning techniques for further improvement.

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