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AUTOMATIC IMAGE RESTORATION USING HYBRID FILTERS FOR DENOISING AND CONTRAST ENHANCEMENT

Dumpa Geetha[1,a], Vempadapu Namratha[1,b,] Ravva Sandyarani[1c], Karri Dhanush[1d], Tammineni Santhosh[1e], Anantha rao Gondu[1,f]

[1a:] Assistant Professor, Department of ECE, Avanthi Institute of Engineering & Technology, Cherukupally, Near Tagarapuvalasa Bridge.

1b, c, d, e: UG Students, Department of ECE, Avanthi Institute of Engineering & Technology, Cherukupally, Near Tagarapuvalasa Bridge

1f: Professor, Department of ECE, Avanthi Institute of Engineering & Technology, Cherukupally, Near Tagarapuvalasa Bridge.

Corresponding Author f: ananth.gondu@gmail.com

Abstract: Underwater images often suffer from color distortion, low contrast, and haze due to light absorption and scattering in the aquatic environment. This work presents a comprehensive and GPU-accelerated hybrid enhancement pipeline for underwater images using MATLAB. The proposed method integrates multiple image processing techniques to improve visual quality and restore natural colors. The enhancement steps include Underwater White Balancing (UWB), Laplacian of Gaussian filtering, Contrast Limited Adaptive Histogram Equalization (CLAHE) with Gaussian smoothing, gamma correction, and Multi-Scale Retinex with Color Restoration (MSRCR). Further refinement is achieved through unsharp masking, Non-Local Means (NLM) filtering, bilateral filtering, anisotropic diffusion, and guided filtering. The pipeline leverages GPU computation when available to accelerate processing. Visual results at each stage are displayed, and the final enhanced image is saved along with intensity histograms for comparison. This approach provides a robust solution for enhancing the quality of underwater images in both research and practical applications

1. INTRODUCTION

Image processing is a multidisciplinary field of study that focuses on analyzing, manipulating, enhancing, and extracting useful information from digital images. At its core, it involves the application of mathematical operations and algorithms to convert an image into a more desirable form or to extract specific features that can be used for further interpretation or decision-making.In the modern era, where digital imagery is ubiquitous—from smartphones and surveillance systems to satellites and scientific instruments—image processing serves as a **bridge between raw image data and intelligent systems** that understand or utilize that data.

The physical properties of light in underwater environments lead to uneven illumination and poor colour rendition. As light travels deeper into the water, longer wavelengths (such as red and orange) are absorbed rapidly, while shorter wavelengths (such as blue and green) penetrate further, resulting in images that are predominantly bluish or greenish in tone. The presence of suspended particles, organic matter, and sediments further exacerbates this problem by introducing scattering effects. Backscattering causes veiling and blurring of the image, while forward scattering leads to uneven lighting and further loss of detail. These combined effects drastically reduce the visibility range and compromise the clarity of the captured images. Consequently, traditional image enhancement techniques struggle to effectively restore underwater visuals without introducing artifacts, excessive sharpening, or noise amplification.

While several filtering and image enhancement methods exist to improve image quality, each comes with its own limitations. Spatial domain filters like median and Gaussian filters are computationally efficient and good at removing some noise, but they tend to blur image details and struggle with complex distortion patterns. Frequency domain approaches can correct specific degradation types but often require precise tuning and fail under varying environmental conditions. More recently, deep learning-based enhancement methods have shown promising results by learning image features from large datasets. However, these methods are computationally intensive, require annotated training data, and are less practical for real-time or embedded underwater imaging systems. They also may not generalize well to underwater conditions that were not present in the training data, leading to inconsistent results.

To address these challenges, the present project proposes a robust and efficient hybrid image enhancement framework designed specifically for underwater environments. The key innovation in this project is the integration of multiple classical image enhancement and filtering techniques into a sequential pipeline, where each method is strategically chosen and placed to address a specific type of degradation.

2. RELATED WORK

Underwater image enhancement has been an active area of research due to the inherent challenges in underwater imaging, such as light absorption, color distortion, scattering, and low contrast. Over the years, several enhancement techniques have been proposed to overcome these limitations.

Traditional image enhancement methods such as Histogram Equalization (HE) and Contrast Limited Adaptive Histogram Equalization (CLAHE) have been widely used for contrast improvement. However, these methods often result in over-enhanced or noisy outputs when applied to underwater scenes.

Color correction approaches like White Balance (WB) and Gray World Assumption have been introduced to address the issue of color cast, where underwater images tend to be overly blue or green. More advanced techniques like Underwater White Balance (UWB) aim to balance color channels based on statistical normalization, thereby restoring natural colors.

Several filtering techniques have also been employed for edge and detail enhancement. Filters like Laplacian of Gaussian (LoG) and Unsharp Masking enhance edge information but may amplify noise. Gamma correction and Multi-Scale Retinex with Color Restoration (MSRCR) are frequently used for illumination correction and dynamic range compression.

For denoising, methods like Non-Local Means (NLM), Bilateral Filtering, and Anisotropic Diffusion have shown significant promise. These methods aim to reduce noise while preserving important image features such as edges and textures. Guided Filtering, being both efficient and edge-aware, has been widely adopted in recent years for post-processing.

3. METHODOLOGY

System Overview:

The hybrid enhancement framework comprises the following major stages:

- **Original Underwater Image Input:** Raw underwater images exhibiting various degradations are loaded into the system.
- **Colour Correction:** Corrects the unnatural blue/green colour cast using gamma correction, MSRCR, and white balancing.
- **Detail Enhancement:** Enhances textures and edges using Unsharp Masking and Laplacian of Gaussian (LoG).
- **Contrast Enhancement:** Improves visibility in darker or hazy regions using CLAHE and histogram-based techniques.
- **Noise Reduction:** Suppresses different types of noise using Non-Local Means (NLM), bilateral filtering, and anisotropic diffusion.
- **Refinement & Fusion:** Guided filtering is used at the final stage to combine enhancements and smooth transitions while preserving structure.
  - **Output Image Display & Metrics:** Final enhanced image is displayed along with quantitative metrics (PSNR, SSIM, etc.).

System Component and Design:

3.1 Input image loader

- Underwater images (RGB format) from diverse datasets will be used.
- Images may suffer from issues such as color cast, blur, turbidity, and noise.

3.2 Colour Correction Block

- Gamma Correction: Adjusts global brightness to restore proper intensity levels.
- White Balancing: Neutralizes color cast by balancing RGB channels.
- Multi-Scale Retinex with Color Restoration (MSRCR): Recovers natural colors and illuminates shadowed regions by simulating human vision.

Mathematical Model (MSRCR)

$$MSRCR(x,y)=G(x,y)\cdot\log(F(x,y)I(x,y))$$

Where III is the input image, FFF is the filtered image, and GGG is the gain factor.

3.3 Detail Enhancement Block

- **Unsharp Masking (UWB):** Sharpens edges by subtracting a blurred version from the original.
- **Laplacian of Gaussian (LoG):** Highlights edges and fine structures for visual enhancement.

3.4 Contrast Enhancement

- CLAHE (Contrast Limited Adaptive Histogram Equalization): Enhances local contrast adaptively to avoid over-amplification of noise.
- Global Histogram Stretching/Equalization: Adjusts dynamic range of intensity values.

3.5 Denoising Block

- **Gaussian Smoothing**: Reduces mild Gaussian noise.
- **Non-Local Means (NLM):** Removes repetitive noise patterns by averaging similar patches.
- **Bilateral Filter**: Edge-preserving smoothing of textures.
- **Anisotropic Diffusion Filter:** Enhances regions while preserving edges during noise reduction.

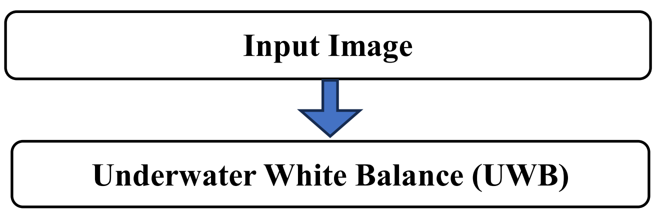
3.6 Refinement Block

- **Guided Filtering:** Fine-tunes enhancement results by refining structure, suppressing halos, and retaining object boundaries.

3.7 Performance Optimization

- **Automated Selection of Filters:** Reduces manual parameter tuning, making the system fully automatic.
- **Hybrid Filtering Approach:** Combines spatial domain filters (e.g., Median, Gaussian) for noise removal.
- **Real-Time Processing Optimization:** Implements GPU acceleration to enhance processing speed.
- **Quality Enhancement & Performance Evaluation:** Improves image metrics such as Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM).
- **Underwater White Balancing (UWB):** Compensates for color distortion caused by wavelength absorption, especially restoring reds and correcting green/blue dominance.
- **CLAHE with Gaussian Smoothing:** Improves local contrast while Gaussian smoothing prevents over-enhancement and preserves visual naturalness.

FLOW CHART:



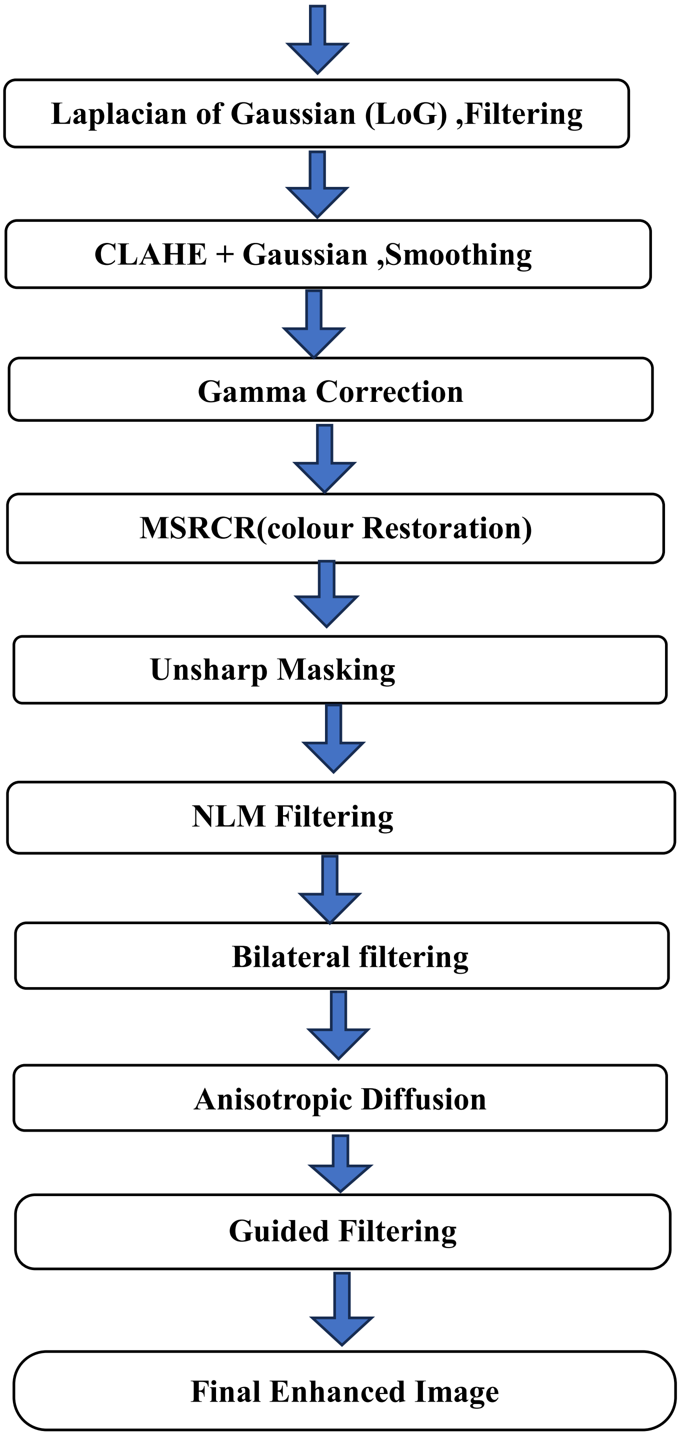


Figure 3.1 Flow chart

- **Input Underwater Image:** This block represents the initial step of loading the input image. The image is selected via a file dialog and read into the system. Underwater images often suffer from color cast, low contrast, and poor visibility due to the scattering and absorption of light underwater. This input serves as the raw data to be processed.

- **GPU Check and Conversion:** Here, the system checks whether a **GPU (Graphics Processing Unit)** is available. If available, the image is converted into a GPU array using MATLAB's gpuArray() function. This enables parallel computation and accelerates the processing of image enhancement steps, especially in real-time or high-resolution scenarios.
- **Underwater White Balance (UWB):** This block performs **color correction** by normalizing the red and blue channels with respect to the green channel. It aims to mitigate the green-blue color cast often seen in underwater images due to wavelength-dependent absorption. This step restores a more natural and balanced color appearance.
- **Laplacian of Gaussian (LoG) Filter:** This block is used for **detail enhancement** and **edge detection**. The LoG filter sharpens the image by emphasizing edges and textures while reducing gradual intensity changes. It combines Gaussian smoothing (to reduce noise) with Laplacian filtering (to detect edges).
- **CLAHE + Gaussian Smoothing:** Here, **Contrast Limited Adaptive Histogram Equalization (CLAHE)** enhances local contrast, making features in darker or brighter regions more visible. After CLAHE, **Gaussian Smoothing** is applied to suppress noise introduced during histogram equalization. This combination improves overall image clarity while maintaining visual balance.
- **Gamma Correction:** This step adjusts the **luminance** of the image non-linearly using a gamma function. A gamma value less than 1 (e.g., 0.8) brightens the image, revealing more detail in underexposed regions. It improves perceptual quality and prepares the image for further enhancement.
- **Multi-Scale Retinex with Color Restoration (MSRCR):** This block mimics the way the human visual system perceives scenes under varying lighting conditions. **MSRCR** enhances image details across multiple scales and simultaneously restores natural colors. It is particularly effective for underwater scenes where lighting is uneven and color is distorted.
- **Unsharp Masking:** This classic image sharpening technique enhances fine details by subtracting a blurred version of the image from the original. It is applied to the output of the MSRCR stage to emphasize edges and textures without introducing significant noise.
- **Non-Local Means (NLM) Filtering:** NLM is a **denoising** algorithm that removes random noise while preserving image structure. Unlike traditional filters, NLM compares and averages similar patches across the image rather than relying only on spatial proximity. This allows for better edge preservation and smoothness.
- **Bilateral Filtering:** This edge-preserving smoothing technique reduces noise while maintaining sharp edges. It considers both spatial closeness and intensity similarity between pixels, making it ideal for refining the output of the NLM stage.
- **Anisotropic Diffusion:** Also known as Perona-Malik diffusion, this process smooths homogeneous areas while preserving edges. It's applied channel-wise to the RGB image, further reducing noise and artifacts without blurring important features.
- **Guided Filtering:** This fast, edge-preserving filter uses a guidance image (often the input image itself) to direct the smoothing process. It enhances the final result by

removing minor artifacts introduced during previous stages while maintaining structure and details.

- **Output Final Enhanced Image:** The final enhanced image, after all processing steps, is displayed and saved. It has improved color balance, contrast, detail, and reduced noise—making it significantly more informative and visually pleasing compared to the original.
- **Histogram & Comparison Plot:** This block generates a visual comparison between the original and final images. Histograms of grayscale intensity are plotted to show the distribution shift, highlighting the contrast enhancement and intensity correction achieved by the system.

4. RESULT

Input Image:

Color corrected Image:

Detailed Enhancement of an Image:

Contrast Enhancement of an Image:

Final Output:

Final View of the Output:

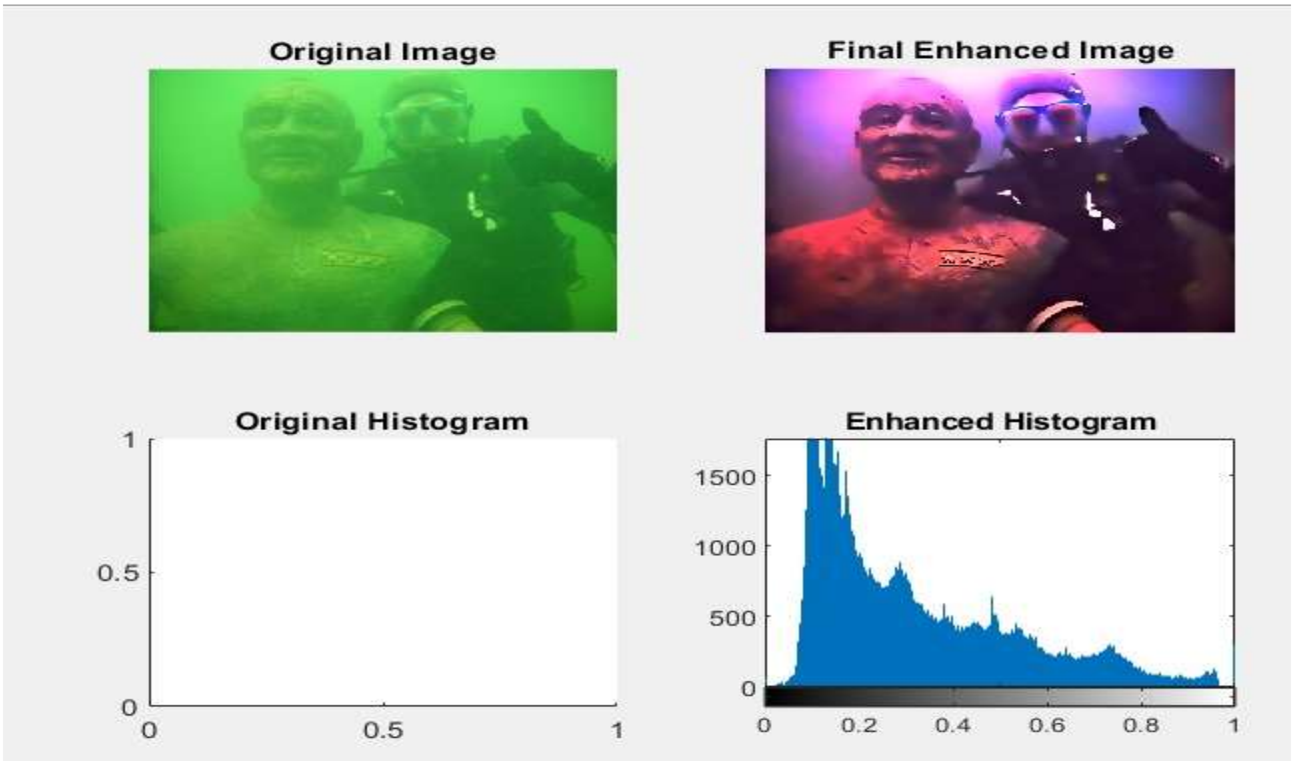


Figure :4.1 : Final view of the Image

5. CONCLUSION

Hybrid filtering techniques enhance degraded images by combining multiple filters, effectively addressing challenges like noise, blur, and detail preservation. Unlike single-filter methods, hybrid approaches use the strengths of various filters—such as median, bilateral, and wavelet filters—to achieve a balance between noise reduction and edge/detail retention. These methods are especially useful in fields like medical imaging, surveillance, and satellite photography, where image quality directly affects outcomes. MATLAB-based experiments show that hybrid filtering consistently outperforms traditional methods in metrics like PSNR, SSIM, and MSE. While hybrid techniques offer superior restoration, they come with higher computational demands and require careful tuning. Future advancements are expected to integrate AI and machine learning to automate and optimize filter selection and performance, making hybrid filtering smarter and more adaptive. In summary, hybrid filtering is a powerful, flexible solution for modern image restoration, with strong potential for further innovation and real-world impact.

Future Scopes

The proposed hybrid filter-based image restoration method shows promising results in terms of both denoising and contrast enhancement. However, there is considerable potential for future enhancements and extensions in this domain: 1. Integration with Deep Learning Models 2. Real-time Implementation. 3. Adaptive and Intelligent Filtering. 4. Application to Video 5. Multimodal Image Fusion

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