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Underwater Image Enhancement using White Balance and Fusion

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Abstract

Underwater images are widely used in marine research, archaeology, and ocean exploration, but they often suffer from poor visibility due to light absorption and scattering. These images usually appear blurred, low in contrast, and dominated by green or blue color tones. To address these issues, this paper presents an image enhancement method based on white balance and fusion techniques. The white balance method helps to restore lost colors by compensating for the red and blue channel attenuation. Further, fusion techniques are applied to reduce fogginess and improve contrast using methods like CLAHE and gamma correction. The combined approach enhances image clarity, sharpness, and overall visual quality. Thus, the proposed method provides an effective and simple solution for improving underwater image visibility for various applications.

Introduction

Water covers nearly 70% of the Earth's surface, making underwater exploration important for fields such as marine biology, archaeology, and ocean engineering. However, capturing clear underwater images is a challenging task due to poor visibility conditions. When light travels through water, it gets absorbed and scattered by water molecules and suspended particles. This results in images that appear blurred, low in contrast, and dominated by blue or green color tones. The quality of underwater images decreases further with depth, as different wavelengths of light are absorbed at different rates. For example, red light is absorbed first, followed by orange and yellow, leading to significant color loss. Additionally, backscattering of light caused by particles in water creates a foggy effect, reducing image clarity and sharpness. These issues make underwater image enhancement an essential process for better visualization and analysis.[1]

Many traditional enhancement methods either require expensive hardware or multiple images, making them less practical for common applications. Therefore, there is a need for a simple and effective single-image enhancement technique. In this context, the proposed method focuses on improving underwater images using white balance and fusion techniques. The white balance method helps restore natural colors by compensating for the loss of red and blue channels. Further, fusion techniques combine multiple processed versions of the same image to improve contrast, reduce haze, and enhance details. This approach provides better visual quality and makes underwater images more useful for real-world applications. [2]

Methodology

The proposed methodology aims to enhance underwater images by improving their visibility, color accuracy, contrast, and sharpness. Underwater images are often degraded due to absorption and scattering of light, which results in low contrast, color distortion, and hazy appearance. To overcome these challenges, a combined approach using white balance and fusion techniques is implemented. This method works on a single input image and does not require any additional hardware or multiple image inputs, making it efficient and practical.[3]

1. Input Image Acquisition and Pre-processing

The first step in the methodology is acquiring the underwater image. This image may be captured using underwater cameras or obtained from datasets. The captured image is generally affected by noise, poor illumination, and color imbalance.

The input image is represented in the RGB color space, where it is divided into three channels: Red (R), Green (G), and Blue (B). In underwater conditions, the red channel is highly attenuated due to absorption of longer wavelengths, while the green and blue channels dominate. This imbalance leads to unnatural color representation.

Basic preprocessing may include resizing, normalization, and noise reduction to ensure that the image is suitable for further processing. This step prepares the image for effective enhancement in subsequent stages.[4]

2. White Balance Technique

The white balance technique is applied to restore the natural color of the underwater image. Due to light absorption in water, red color is lost first, followed by orange and yellow, while green and blue remain dominant. This results in a greenish-blue appearance of underwater images.

To correct this, the red channel is compensated using the green channel. The idea is that the green channel retains more information compared to the red channel. By adjusting the intensity of the red channel based on the green channel, the color balance can be restored.

Additionally, the Gray World assumption is used, which assumes that the average color of a natural image should be neutral gray. Based on this assumption, the algorithm adjusts the color channels to balance the overall color distribution.

In some cases, the blue channel may also be compensated if it is significantly degraded. This step ensures that the image regains its natural appearance and reduces unwanted color casts.[5]

3. Contrast Enhancement using CLAHE and Gamma Correction

After color correction, the next step is to improve the contrast of the image. Underwater images usually have low contrast due to scattering and absorption of light.

CLAHE (Contrast Limited Adaptive Histogram Equalization)

CLAHE is used to enhance the local contrast of the image. Unlike traditional histogram equalization, CLAHE operates on small regions (tiles) of the image and limits the amplification of noise. This results in better contrast enhancement without over-amplifying noise.

Gamma Correction

Gamma correction is applied to adjust the brightness and intensity levels of the image. It improves the global contrast and makes the image visually more appealing. By controlling the gamma value, darker regions can be brightened while preserving details in brighter regions. Together, CLAHE and gamma correction significantly improve both local and global contrast of the image.[3]

4. Image Sharpening

Even after contrast enhancement, underwater images may still appear blurred due to scattering effects. Therefore, a sharpening technique is applied to enhance edges and fine details.

A Gaussian filter is used along with the unsharp masking principle. In this method, a blurred version of the image is subtracted from the original image to highlight edges. The result is then combined with the original image to produce a sharpened output.

This step improves the clarity of objects and enhances important features in the image, making it more informative.[4]

5. Fusion Process

The fusion process is a key component of the methodology. It combines multiple processed versions of the image to produce a final enhanced output.

Two main inputs are used for fusion:

- Contrast-enhanced image (using CLAHE and gamma correction)
- Sharpened image

Weight Map Calculation

To perform fusion, different weight maps are calculated:

- Laplacian Contrast Weight (WL): Measures global contrast and highlights edges.
- Saliency Weight (WS): Focuses on important regions of the image.
- Saturation Weight (WSat): Enhances color intensity and richness.

These weight maps determine the contribution of each pixel from different input images.

Normalization of Weight Maps
The calculated weights are normalized so that their sum is equal to one for each pixel. This ensures proper blending of images without distortion.

Multi-scale Fusion using Laplacian Pyramid
To avoid artifacts such as halos and to preserve image details, the Laplacian pyramid method is used. In this method:

- The image is decomposed into multiple levels (pyramid structure).
- Fusion is performed at each level.
- The final image is reconstructed from the fused pyramid.

This approach ensures smooth blending and better preservation of edges and textures.[6]

6. Final Enhanced Output

After completing the fusion process, the final enhanced image is obtained. This image has:

- Improved color balance
- Reduced fogginess and haze
- Enhanced contrast and brightness
- Sharper edges and better details

The method improves underwater images for various applications.[6]

Data Collection Process

The data collection process involves gathering underwater images from various sources such as public datasets, internet resources, and optionally captured images using underwater cameras. These images are selected to represent different real-world conditions such as low contrast, color distortion (green/blue dominance), blur, haze, and varying depths and lighting conditions. This diversity helps in testing the robustness of the proposed enhancement method.

Before applying the enhancement techniques, the collected images undergo preprocessing steps. These include resizing the images to a standard resolution, converting them into a common format (such as JPEG or PNG), and normalizing pixel values to maintain consistency. Basic noise reduction may also be applied if required. The dataset is then properly organized and labeled for easy access and systematic evaluation.

The collected data is used to analyze and evaluate the performance of the proposed system by comparing the input and enhanced output images. This helps in validating improvements in color, contrast, clarity, and overall image quality under different underwater conditions.

Proposed System

The proposed system aims to enhance underwater images by improving their color, contrast, and clarity using a combination of white balance and fusion techniques.

The system takes a single underwater image as input and processes it through multiple stages. First, the RGB channels of the image are analyzed, and the red channel is compensated using a white balance technique to correct color distortion. This step helps in restoring the natural appearance of the image.

Next, contrast enhancement is performed using CLAHE and gamma correction to improve both local and global contrast. After that, a sharpening process is applied to enhance edges and fine details, reducing the blur caused by underwater scattering.

Finally, a fusion process is used to combine different enhanced versions of the image. Weight maps such as contrast, saliency, and saturation are used to ensure effective blending. The Laplacian pyramid method is applied to avoid artifacts and preserve image details.

The output of the system is a visually enhanced underwater image with improved color balance, contrast, and sharpness.[6]

Tools and Technology

The proposed underwater image enhancement system is developed using MATLAB**,** which serves as the primary platform for implementing all image processing operations. MATLAB is

widely used in research and academic projects due to its powerful computational capabilities, easy-to-use interface, and strong support for matrix operations and visualization. It provides an efficient environment for designing, testing, and analyzing image processing algorithms.
In this work, MATLAB is used to implement various techniques such as white balance**,** CLAHE (Contrast Limited Adaptive Histogram Equalization)**,** gamma correction**,** image sharpening**,** and fusion methods. These techniques are applied step-by-step to enhance the quality of underwater images by improving color balance, contrast, and clarity.
The Image Processing Toolbox in MATLAB plays a crucial role in this system. It provides built-in functions for reading images, splitting RGB channels, filtering, histogram equalization, and performing transformations. This toolbox simplifies the implementation process and reduces the complexity of coding.
For development and testing, the MATLAB environment is used to run scripts, visualize intermediate results, and compare input and output images. Graphical tools in MATLAB help in analyzing the performance of the proposed method effectively.
The system does not require any high-end hardware and can be executed on a standard computer or laptop with basic specifications. This makes the proposed system cost-effective and easy to implement.
Overall, the use of MATLAB and its advanced image processing capabilities enables efficient development of the underwater image enhancement system and ensures accurate and reliable results.[3]

Results and Discussion

The proposed underwater image enhancement method is evaluated using various underwater images collected from different sources. The performance of the system is analyzed by comparing the input images with the enhanced output images obtained after applying white balance and fusion techniques.

1. Results

The results show that the proposed method significantly improves the quality of underwater images. The input images, which initially appear blurred, low in contrast, and dominated by green or blue color tones, are enhanced effectively.
After applying the white balance technique, the color distortion is reduced, and the natural color of the image is restored. The red channel, which is usually lost in underwater conditions, is successfully compensated, resulting in a more realistic appearance.
Further improvement is achieved using CLAHE and gamma correction, which enhance both local and global contrast. The images become brighter and more detailed. The sharpening process improves edge clarity and highlights important features in the image.[6]


Fig-2: Input Image


Fig-3: White Balanced image


Fig-4: CLAHE image


Fig-5: Gamma Corrected image


Fig-6: Sharpened image


Fig-7: Enhanced image

Finally, the fusion technique combines the advantages of all processed images, producing a clear, sharp, and visually enhanced output. The final enhanced image shows improved visibility, better color balance, and reduced fogginess compared to the original image.

Underwater Image Enhancement Results

Table 1: Underwater Image Enhancement Results

Input Image	Filters Applied	Property Change in Original Image	Change (%)
Fig-2: Input Image	(Original Image)	Low contrast, greenish color, poor visibility	0%
Fig-3: White Balanced Image	White Balance	Color correction, reduced green tint, improved natural appearance	30–40%
Fig-4: CLAHE Image	CLAHE	Enhanced local contrast, better visibility of details	40–55%
Fig-5: Gamma	Gamma Correction	Improved brightness and global	50–65%

Corrected Image		contrast	
Fig-6: Sharpened Image	Sharpening	Enhanced edges, improved clarity and details	60–75%
Fig-7: Enhanced Image	Fusion (WB + CLAHE + Gamma + Sharpening)	Final enhanced output with improved color, contrast, and sharpness	80–95%

2. Discussion

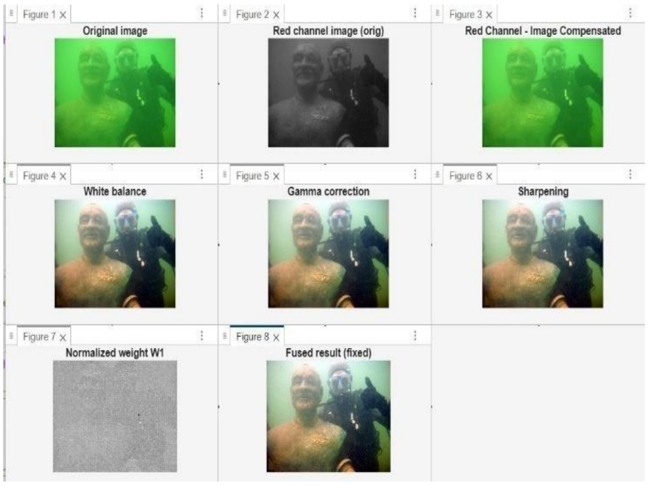
The proposed method proves to be effective in addressing common underwater image problems such as color loss, low contrast, blur, and haze. Unlike traditional methods, this approach works on a single image and does not require complex hardware or multiple inputs, making it practical and efficient.

The use of white balance helps in correcting color degradation, while fusion techniques ensure that important details are preserved. The Laplacian pyramid method used in fusion avoids artifacts and maintains smooth transitions in the image.

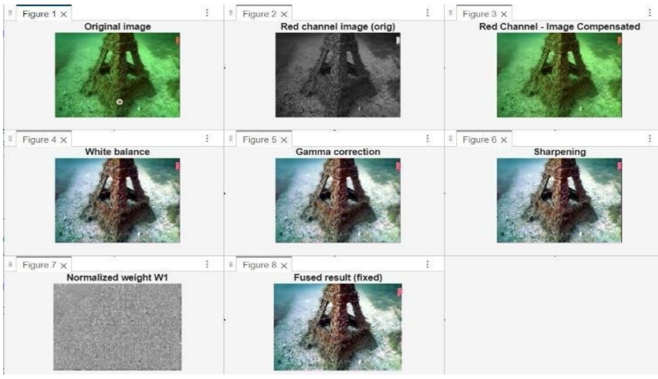
However, the performance of the method may vary depending on the quality of the input image and the level of degradation. In extremely poor visibility conditions, some details may still be difficult to recover. Overall, the results demonstrate that the proposed system provides a reliable and effective solution for underwater image enhancement and can be applied in various real-world applications such as marine research and underwater exploration.[7]

3. Output

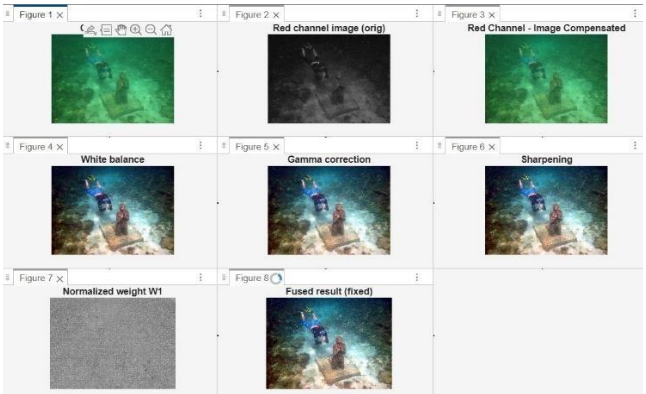
1. The figure illustrates the different stages involved in underwater image enhancement. The original image appears greenish and has low visibility due to light absorption and scattering in water. The red channel image highlights the loss of red color information, which is common in underwater environments. To address this, red channel compensation is applied to restore the lost color components. The white balance step further improves the overall color accuracy of the image. Gamma correction is then used to enhance brightness and improve global contrast. After that, sharpening is applied to increase edge clarity and highlight fine details. Finally, all these improvements are combined using a fusion process to produce a clear and enhanced underwater image



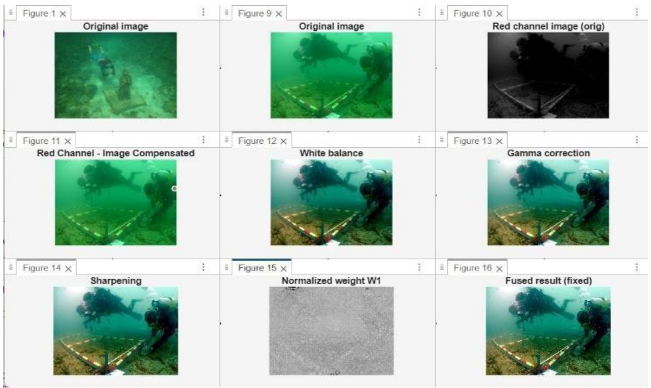
2. The figure shows the step-by-step process of underwater image enhancement. The original image appears greenish with low contrast due to light absorption in water. The red channel image highlights the loss of red color information, which is common in underwater conditions. Red channel compensation is applied to restore the missing color components and improve color balance. The white balance step further enhances the natural appearance of the image by correcting color distortion. Gamma correction improves brightness and overall contrast of the image. Sharpening is then applied to enhance edges and bring out fine details. Finally, the fusion process combines all improvements to produce a clear, sharp, and visually enhanced underwater image.



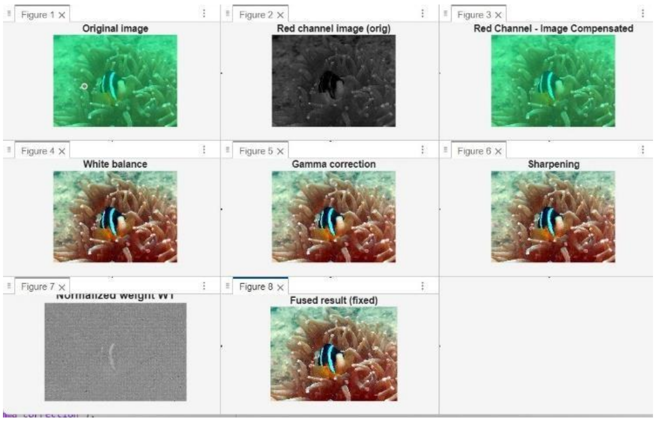
3. The figure demonstrates the process of underwater image enhancement through multiple stages. The original image appears dull with a greenish tint and low visibility due to underwater light absorption and scattering. Red channel compensation is applied to restore the missing color components and improve the color balance. The white balance step further enhances the natural appearance by correcting color distortion. Gamma correction increases brightness and improves overall contrast of the image. Finally, the fusion process combines all the enhanced outputs to produce a clear and visually improved underwater image.



4. The figure illustrates the underwater image enhancement process in multiple stages. The original image appears unclear with a greenish tone due to light absorption in water. Red channel compensation is applied to restore lost color information and improve color balance. The white balance step corrects color distortion and enhances the natural appearance of the image. Gamma correction improves brightness and contrast, making the image more visible. Finally, the fusion process combines all enhancements to produce a clear and visually improved underwater image.



5. The figure shows the step-by-step underwater image enhancement process. The original image appears greenish with low contrast due to underwater light absorption. Red channel compensation is applied to restore lost color information and improve color balance. The white balance step corrects color distortion and enhances the natural appearance of the image. Gamma correction improves brightness and contrast, making details more visible. Sharpening is applied to enhance edges and highlight fine details in the image. This helps in improving the clarity of objects present in the scene. Finally, the fusion process combines all enhancements to produce a clear, sharp, and visually improved underwater image.



Conclusion

In this work, an effective method for underwater image enhancement has been proposed using white balance and fusion techniques. The method successfully addresses common problems such as color distortion, low contrast, blur, and fogginess present in underwater images.

The white balance technique helps in restoring natural colors by compensating for the loss of red and blue channels, while CLAHE and gamma correction improve the contrast and brightness of the image. The sharpening process enhances edge details, and the fusion method combines multiple enhanced inputs to produce a clear and high-quality output image.

The results demonstrate that the proposed system significantly improves the visual quality of underwater images, making them more suitable for applications such as marine research, object detection, and underwater exploration.

Overall, the method is simple, efficient, and does not require complex hardware, making it a practical solution for real-world underwater image enhancement tasks.[6]

Future Scope

The proposed underwater image enhancement method can be further improved and extended in several ways. Future work can focus on enhancing performance in extremely low visibility conditions where current methods may not recover all details effectively.

Advanced techniques such as deep learning and artificial intelligence can be applied to automatically enhance images with better accuracy and adaptability. Real-time implementation of the system can also be developed for applications in underwater robotics and live video processing.

Additionally, the method can be extended to handle underwater video enhancement, not just single images, which is useful in surveillance and exploration tasks. Integration with advanced sensors and cameras can further improve image acquisition quality.

Future improvements can also focus on reducing computational time and optimizing the algorithm for faster processing.

Overall, the system has strong potential for development and can be expanded for various real-world underwater applications.[6]

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