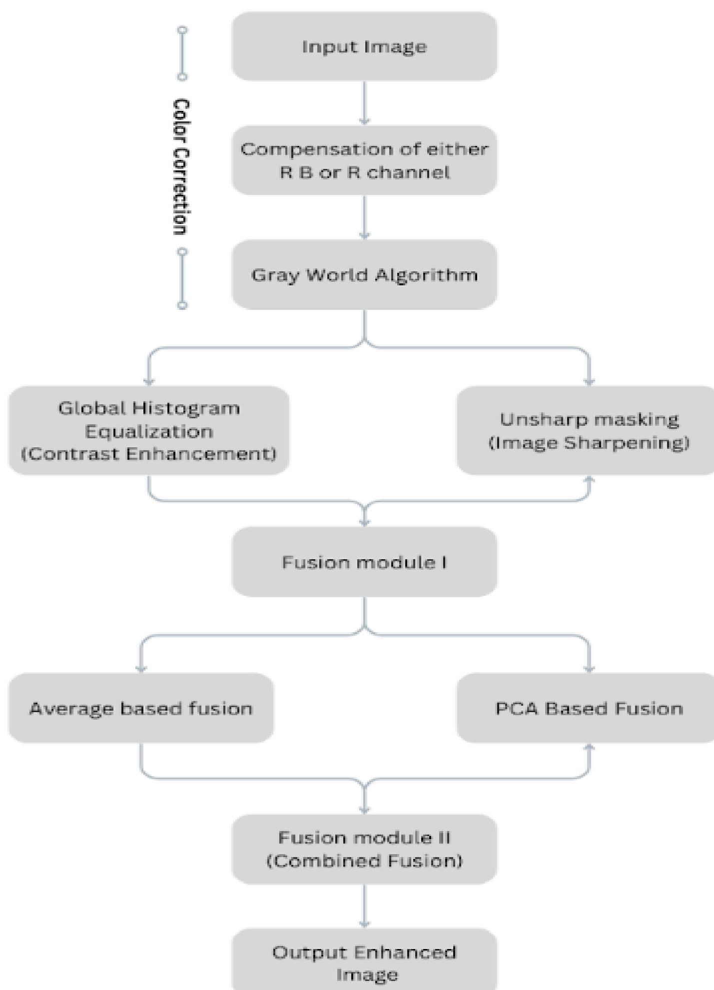
UNDERWATER IMAGE ENHANCEMENT USING MULTI-FUSION TECHNIQUE

The proposed system extracts different features from the input underwater image using white balance correction, contrast enhancement, and dehazing techniques. These processed images are then fused using a weighted fusion algorithm to generate a high-quality output image. The fusion process effectively combines the advantages of each enhancement technique, ensuring better visibility, edge sharpness, and color accuracy.

Work-flow of the proposed work



4.2. APPROACH

Step-1: Initial Image Analysis

Underwater images typically exhibit a bluish or greenish tint because of the absorption and scattering of light. Longer wavelengths (red) are absorbed more rapidly in water compared to shorter wavelengths (blue and green). As a result, the red and blue channels in the image suffer degradation, leading to a loss of color accuracy and balance. We begin our enhancement process by analyzing the histograms of the Red, Green, and Blue channels

This analysis reveals that the Red channel is typically concentrated toward the left side of the histogram, indicating a significant reduction in its intensity due to light absorption. Similarly, the Blue channel often shows a similar concentration in images with a greenish tint. These initial observations help guide the subsequent color correction process, where the goal is to compensate for this degradation and restore a more natural color balance.

Step-2: Compensation for Degraded Color Channels

The next key step is compensating for the degradation of the Red and Blue channels, which are most affected by underwater conditions. The Green channel, being less degraded, serves as a reference for restoring the color balance in the image. By adding a fraction of the Green channel to the Red and Blue channels, we effectively compensate for the loss of color in these channels.

The formula for this compensation takes into account the mean value of each channel and uses the difference between the current value and the reference Green channel to determine the necessary adjustment. The formula for the compensated red channel Irc at every pixel location (x)

$$Irc(x) = Ir(x) + (g - r) * (1 - Ir(x)) * Ig\, I\, I\, (x) \text{ -(1)}$$

The formula for the compensated blue channel Ibc at every pixel location (x)

$$Ibc(x) = Ib(x) + (g - b) * (1 - Ib(x)) * Ig\, I\, I\, (x) \text{ - (2)}$$

Ir, Ig represent the red and green color channels of the image I, *I*r, *I*g, *I*b denote the mean value of Ir , Ig , and Ib respectively.

Step-3: White Balancing using the Gray World Algorithm

After compensating for color degradation, the next step is white balancing, which ensures that the image's overall color tone is corrected for any color cast. The Gray World algorithm is employed to perform this correction, based on the assumption that the average color of the image should be achromatic (gray). The algorithm works by adjusting the RGB channels to ensure that the average color of the scene appears neutral. While the compensation step restores the individual channels, the Gray World algorithm ensures that the overall color balance is improved. After applying this algorithm, the image undergoes significant color correction, resulting in an image with more accurate and visually appealing color representation. However, while color balance is achieved, the image still suffers from low contrast, and fine details remain hard to discern.

For an image with color channels R, G, and B, the Gray World Algorithm formula is:

$$R_{\text{new}}(x,y) = \frac{R(x,y)\cdot M_G}{M_R}, \quad G_{\text{new}}(x,y) = G(x,y), \quad B_{\text{new}}(x,y) = \frac{B(x,y)\cdot M_G}{M_B}$$

Where,

R(x,y) ,G(x,y) ,B(x,y): Pixel values of the red, green, and blue channels at position (x,y)(x, y)(x,y).

Mr,Mg,Mb: Mean values of the red, green, and blue channels across the entire image.

Rnew(x,y) ,Gnew(x,y), Bnew(x,y): New white-balanced pixel values for the red, green, and blue channels.

The green channel G(x,y) is often chosen as the reference because it is less prone to absorption in natural scenes.

Step-4: Contrast Enhancement through Global Histogram Equalization

One of the most common issues in underwater images is poor contrast, especially in darker regions. To address this, we apply Global Histogram Equalization (GHE), which is a technique that redistributes the intensity values of the image to enhance the contrast across the entire image. GHE operates by first converting the image from the RGB color space to the HSV (Hue, Saturation, Value) color space. The Value component of the image corresponds to the brightness of the image, and by equalizing this component, we can enhance the contrast. Once the Value component is equalized, the original Hue and Saturation components are retained, and the new enhanced Value component is concatenated with them. This process results in a contrast-enhanced image where details in darker regions are made more visible, and the overall dynamic range of the image is improved.

Histogram Equalization is a technique to redistribute the pixel intensities of an image such that the histogram becomes uniform. For an image with L intensity levels (0 to L−1), the GHE formula is:

$$s_k = \text{round}\left((L-1)\frac{\sum_{j=0}^{k} p_j}{N}\right)$$

Where:

Sk: New intensity value for level k.

Pj: The number of pixels at intensity level j.

N: Total number of pixels in the image.

L: Total number of intensity levels (e.g., 256 for an 8-bit image).

k: Current intensity level ranging from 0 to L−1.

Step-5: Edge Sharpening with Unsharp Masking

While GHE enhances the contrast, it often introduces a soft or blurry appearance to the image, which reduces the clarity of fine details. To counter this, we apply unsharp masking to sharpen the edges and restore detail in the image. Unsharp masking involves subtracting a blurred version of the image from the original, emphasizing the high-frequency components[14] of the image, such as edges. A Gaussian blur is first applied to the image, and the difference between the original and the blurred image is calculated to create the unsharp mask. This mask is then added back to the original image to sharpen it. The result is a crisper image with more clearly defined edges, which is especially important for applications requiring precise detail, such as underwater object detection or marine biology studies.

gMASK(x, y) = f(x, y) - Gaussian_Blur(f(x, y)) -(5)

g(x, y) = f(x, y) + gMASK(x, y) - (6)

g(x, y) = 2*f(x, y) - Gaussian_Blur(f(x, y)) -(7)

Here, f(x, y) is the image on which we want to perform unsharp masking

Step-6: Fusion of Contrast-Enhanced and Sharpened Images

At this stage, we have two enhanced versions of the image: one with improved contrast (via GHE) and one with enhanced sharpness (via unsharp masking). To combine the strengths of both images, we use image fusion techniques. The goal is to integrate the contrast-enhanced and sharpened images into a single image that retains the high contrast and sharp details from both versions.

In Averaging-based Fusion, the resultant fused image is obtained by taking the average intensity of corresponding pixels from both the input image.

$$F(i,j) = A(i,j) + B(i,j) /2 \quad \text{-------------------(8)}$$

A(i,j), B(i,j) are input images and F(i,j) is a fused image.

Step-7: Final Image of Combined fusion

The Combined Fusion approach creates the final enhanced underwater image by blending the results of PCA Fusion and Average Fusion using a weighted formula

Combined = weight_pca * PCA + (1 - weight_pca) * Average -------- -(9)

This method integrates the sharpness and detail emphasis of PCA Fusion with the smooth transitions and uniform color blending of Average Fusion. By adjusting the fusion weight, the user can prioritize either sharper details or natural color blending, making the approach adaptable to various underwater conditions. The final image exhibits improved color balance, enhanced contrast, and sharp details while maintaining a natural and realistic appearance, effectively minimizing artifacts and providing a visually appealing result.

Metrics Comparison

	Average Fusion			
IMAGE	MSE	PSNR	SSIM	UIQM
1	108.8051594	3.698906909	0.7682058877	45.72419886
2	106.5381364	3.790350848	0.7498721813	48.42412005
3	104.6986865	3.86598947	0.6810355262	53.92730823
4	105.5345569	3.831454895	0.6165936495	43.95465329
5	107.9850864	3.731764004	0.7385638912	51.76241455
6	104.4918715	3.874576726	0.6846033268	49.22329323
7	107.3906649	3.755736492	0.7693179701	66.72800328

	PCA Fusion			
IMAGE	MSE	PSNR	SSIM	UIQM
1	109.4463567	3.673388713	0.7550533134	48.96404687
2	99.16821289	4.101676935	0.7208291538	52.60367746
3	101.9592205	3.981136737	0.6707786251	55.918894
4	101.5182911	3.99995882	0.589870901	49.33293417
5	109.1350589	3.685758931	0.7146738447	55.42937895
6	103.3539486	3.922131069	0.6539465198	53.39862786
7	108.5374613	3.709605211	0.7650788629	67.98769597

	Combined Fusion			
IMAGE	MSE	PSNR	SSIM	UIQM
1	108.3911558	3.715463333	0.7604018441	47.70519745
2	101.6622175	3.993806021	0.7321010713	50.96214694
3	102.9485996	3.939197371	0.674647346	55.07010452
4	101.7458339	3.990235449	0.6013584084	47.23348512
5	109.9623888	3.652960148	0.7237701404	54.00958518
6	104.0101796	3.894643341	0.6647996194	51.78198955
7	107.035296	3.77013166	0.7658577801	67.4787976

Final Comparison Table

Metric	Average Fusion	PCA Fusion	Combined Fusion
MSE	Moderate	Low	Lowest
PSNR	Moderate	Higher	Highest
SSIM	Moderate	Low	Highest
UIQM	High	Higher	Highest

MSE (Mean Squared Error) → Low (Lower error indicates better image quality)

PSNR (Peak Signal-to-Noise Ratio) → High (Higher PSNR means better quality and less distortion)

SSIM (Structural Similarity Index) → High (Higher SSIM indicates better structural similarity with the reference image)

UIQM (Underwater Image Quality Measure) → High (Higher UIQM means better perceptual quality of the enhanced image)