Underwater Image Enhancement Using Image Processing

M.Tech. (Dual Degree) Dissertation

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CERTIFICATE

I hereby certify that the work which is being presented in the M.Tech. Dissertation entitled "**Underwater Image Enhancement Using Image Processing**" in partial fulfillment of the requirements for the award of the Master of Technology (Dual Degree) and submitted to the Department of Electronics & Communication Engineering of National Institute of Technology Hamirpur HP is an authentic record of my own work carried out during a period from July 2022 to June 2023 under the supervision of **. Gagnesh Kumar**, Associate Professor E&CE Department, NIT Hamirpur HP.

The information in this thesis has not been submitted elsewhere for the award of another degree.

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This is to confirm that, to the best of my knowledge, the candidate's above statement is accurate.

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Signature of Supervisor **Signature of External Examiner**

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ABSTRACT

Due to light beam attenuation and scattering brought on by suspended water particles, underwater photographs frequently exhibit low contrast and colour distortion. Before the light reaches the sensor, these particles reflect and deflect it in unforeseen ways, producing blurry, poorly detailed images. Additionally, water absorbs light quickly and at varying rates depending on the wavelength, giving underwater habitats a broad greenish-blue hue. Our research has created an underwater picture enhancing system with three primary parts to address these problems.

Stage 1 focuses on image input and conversion, white balancing, gamma correction, sharpening, and image fusion using wavelet transform. It starts by loading an RGB image and performs white balancing to adjust the color channels based on the mean luminance value. Then, to improve the image, sharpening and gamma correction techniques are used. Finally, the image is fused using wavelet transform and histogram equalization is applied for improved visualization.

Stage 2 involves loading a wavelet-fused image and applying different enhancement methods. The methods include CLAHE in the HSV color space, adaptive gamma correction in the L*A*B color space, color correction using the gray world assumption, and histogram equalization in the RGB color space. Each method aims to enhance the image using specific color space transformations and correction techniques.

In summary, this code demonstrates a comprehensive approach to enhance underwater images by addressing color balance, contrast, gamma correction, and fusion using wavelet transform. Multiple strategies are incorporated at each level to enhance the underwater photographs' overall visual appeal.

Contrast enhancement, color restoration, and preservation of important image details. The algorithm shows great potential for various underwater imaging applications, including underwater photography, marine exploration, and underwater surveillance.

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LIST OF ABBREVIATIONS

Abbreviation	Description
UIE	Underwater Image Enhancement
MSRCR	Multi-scale Retinex with color Restoration
WB	White Balance
HE	Histogram Equalization
UICM	Underwater Image colorfulness Metric
UISM	Underwater Image Sharpness Metric
CCA	Color Correction Algorithm
CLAHE	Contrast Limited Adaptive Histogram Equalization
LAB	CIELAB color space
HSV	Hue, saturation, value color space
RGB	Red, green, blue color model
USM	Unsharp masking
DCP	Dual-Channel Perceptual Color Correction
Retinex	Retina-like theory of color vision
SR	Super Resolution
WF	Wavelet Fusion
CNN	Convolutional Neural Network
ML	Machine Learning

CHAPTER 1

Introduction

The aquatic environment covers a significant portion of the Earth and studying it has become increasingly important due to its impact on the ecosystem. Underwater imagery is a valuable tool for scientific research, marine ecology, aquatic robots, underwater geology, and fish species recognition. It is also essential for offshore facilities such as drinking water reservoirs and underwater cable framework installations. However, the traditional method of visually inspecting these underwater areas using divers is hazardous, time-consuming, and expensive.

To avoid these issues, two solutions have been proposed: using sonar sensors or cameras to capture underwater imagery. Although sonar sensors have advantages, they generate an enormous amount of data that is often challenging to analyze. On the other hand, camera-based imaging modalities have many potential uses. Moreover, camera systems must be waterproof to avoid damaging their sensors.

1.1 Introduction

Underwater imagery provides valuable information for scientific research, marine ecology, and the understanding of underwater geology. However, the traditional method of visually inspecting underwater areas using divers is hazardous, time-consuming, and expensive. Thus, the use of cameras to capture underwater imagery has become increasingly popular. The use of pre-processing algorithms is necessary to obtain clear pictures of the underwater scenery.

Research Introduction:

Underwater images are often difficult to record and process, resulting in a low contrast and blue or green tinge. Diverse methods, such as color correction, contrast enhancement, and fusion-based methods, have been suggested to address these problems and improve underwater photos. In this study, we analyze and assess a variety of underwater picture improvement methods, such as wavelet fusion, color correction, and CLAHE.

1.2 Motivation

However, underwater images are often of poor quality due to the absorption and scattering of light by water, resulting in low contrast, color distortion, and loss of detail. Therefore, there is a need for effective techniques for enhancing underwater images to improve their quality and utility for various applications. The motivation for the above context is to explore and of various techniques for achieving this goal. By improving the quality of underwater images, we can better understand and analyze underwater environments and structures, leading to more informed decision-making in a variety of fields.

1.3 Problem Formulation

The problem formulation for the context of underwater image enhancement with various techniques can be to improve the quality. The objective is to develop and evaluate different methods and algorithms to enhance underwater images, including techniques such as color correction, contrast enhancement using CLAHE, adaptive gamma correction, and super-resolution. The problem formulation can also include the exploration of different color spaces, such as RGB, HSV, and LAB, to determine the most effective method for enhancing the colors and contrast in underwater images. Ultimately, the goal is to provide a set of optimized techniques for underwater image enhancement that can be used.

1.3.1 Problem Statement

The issue addressed in this context is the lack of visibility and color accuracy in underwater. This results in images with low contrast, color cast, and poor visual quality, which can make it difficult to extract useful information from underwater scenes. The problem statement is to develop image processing techniques that can enhance the quality and visibility of underwater images by addressing these issues. The goal is to make the quality of underwater images for various applications such as marine research, underwater exploration, and surveillance

1.4 Methodology

- The methodology for enhancing underwater images using various techniques can be outlined as follows:

- Data Collection: The first step is to collect underwater images that need to be enhanced. These images can be collected using underwater cameras or downloaded from public underwater image datasets.

- Pre-processing: The pre-processing step involves removing any noise, distortion, or artifacts from the images. This can be done using techniques such as denoising, deblurring, and image registration.

- Color Improvement: The images which we are working on often have a blue or green tint due to the absorption and scattering of light by water. Color correction techniques can be used to make improvement of the natural colors in the image to make it look clear. Other color correction methods can also be used depending on the specific characteristics of all the images.

- Contrast Enhancement: Contrast enhancement method can be made to improve our results of input images. One such technique is CLAHE, which can be put to the value space of the HSV color space, L channel of the L*A*B , or the Red Green
    - Blue.

- Fusion-based Techniques: Fusion-based techniques to further get the corners and details pixels values and sharpness of the given images. Techniques such as Laplacian filtering, Unsharp Mask filtering, and wavelet fusion can be used to achieve this.

- Super-resolution: Super-resolution to increase the resolution of the given proper tint and blue images, which can help to reveal finer details.

    - Overall, the methodology involves a mixing up of pre-processing, color improvement, contrast value, fusion-based tricks, and super-resolution to get the clear images. The choice of specific techniques and their parameters may depend on the characteristics of the images and the specific requirements of the application

1.5 Organization of the Thesis

Thesis is on the development of a model for enhancing underwater images using various image processing techniques. The main framework for this project involves exploring different color spaces and applying various methods such as CLAHE, color correction, gamma correction, super resolution, Retinex, and wavelet fusion to enhance the underwater images. The methodology involves implementing these techniques using MATLAB and evaluating the results through visual comparison and quantitative analysis of contrast gain values. The introduction defines the study's goals and provides a thorough description of the research problem. In the literature review, a thorough examination of previous research conducted in this field enhancement is provided. The Part highlights the existing knowledge and identifies the gaps that the current study aims to address. The methodology chapter describes the techniques used in this study and the experimental setup. The results and analysis chapter of the thesis encompasses the presentation of experimental findings and a comprehensive discussion on their significance. This section highlights the outcomes derived from implementing the different methods for enhancing underwater images and thoroughly analyzes their implications. The obtained results are examined in relation to the stated research objectives and provide insights into the effectiveness of each method.

- **Chapter 1**. *Introduction*: Chapter 1 of the thesis provides an overview of the primary motivations behind undertaking the research and clearly states the research objectives and problem statement. This chapter also outlines the approach and implementation of the model used in the study.

- **Chapter 2**. *Literature Survey:* The purpose of this chapter is to present an overview of the existing literature and research in the field. It discusses various technologies used by previous researchers to construct similar systems and enhance the efficiency and speed of earlier models. The chapter also explores the challenges faced in the field, a review of different models, and the methods employed to enhance the model's performance.

- **Chapter 3**: *Optimal Underwater Image Enhancement:* In Chapter 3, Assessing Underwater visibility with acoustic and optical imaging systems. Limitations of current techniques for underwater and hazy images. The chapter concludes with the presentation of results and a comparative analysis of the proposed approach with other related works.

- **Chapter 4.** *Underwater Image Enhancement Techniques:* In Chapter 4, CLAHE in HSV color space, adaptive gamma correction in LAB color space, color correction using the gray world assumption, and histogram equalization in RGB color space. These methods target improving contrast and color balance in underwater images, with the goal of revealing more details and restoring natural colors.

- **Chapter 5**. *Results and Discussion:* The use of color correction and various enhancement techniques such as CLAHE, adaptive gamma correction, histogram equalization, and fusion-based techniques have shown to improve the quality of underwater images by enhancing their color balance, contrast, and sharpness. The choice of technique depends on the specific characteristics of the image, and each technique has its advantages and disadvantages. The results of these best methods can be quantitatively analyzed using contrast gain values and visually compared using side-by-side image comparisons.

- **Chapter 6**. *Conclusion and Future Scope of Work:* The paper's concluding chapter presents a summary of the data obtained and explores potential future research directions. Additionally, it summarizes the research's findings without repeating anything from the prior sections to conclude the study.

CHAPTER 2

Literature Survey

In this research we deal with various techniques proposed in the literature. The primary goal of UIE is to get the best results by applying different algorithm on the images, which are often degraded by the natural phenomena of light by water. The methods for underwater enhancement can be broadly classified into two categories: image restoration methods and IE-based techniques. Restoration techniques aim to remove noise and other degradations from the image, while IE-based techniques try to increase the contrast fullness, color balance, and overall visual quality of the image. The review of the literature reveals that numerous approaches, including color correction, CLAHE, Retinex, gamma correction, and wavelet fusion, among others, have been proposed recently. The technique chosen will rely on the qualities and the desired result. Enhancing underwater images involves modifying the pixel distribution of an image to improve its overall contrast and color appearance. This process aims to mitigate the adverse effects of underwater conditions, such as reduced visibility and color distortion. By applying various techniques, the image's visual quality can be enhanced, allowing for better interpretation and analysis.

Underwater image enhancement techniques often involve adjusting the color balance, contrast, and sharpness of the image. These adjustments help restore or enhance the details and features that may have been lost or distorted due to factors like light attenuation and scattering underwater. By optimizing the distribution of pixel values, the desired enhancements can be achieved.

One common approach is to correct color imbalances by adjusting the color channels to compensate for the dominant color cast caused by underwater conditions. This helps restore more accurate and natural color representation. Additionally, contrast enhancement techniques are applied to expand the range of intensity values and improve the distinction between different objects or regions in the image. This can be achieved through methods such as histogram equalization or adaptive contrast enhancement algorithms.

Another important aspect of underwater image enhancement is sharpening, which aims to enhance image details and edges that may appear blurred or degraded due to scattering and water turbidity. Sharpening techniques involve enhancing high-frequency components to improve the image's overall sharpness and clarity.

By employing a combination of these techniques and adapting them to the specific characteristics of underwater images, it is possible to enhance their visual quality and make them more suitable for analysis, interpretation, and visual presentation. These enhancements can help researchers, scientists, and professionals in various fields gain a clearer understanding of underwater environments and objects captured in the images. Different techniques have been developed to achieve this, ranging from contrast enhancement through HE or CLAHE, to color correction using methods like gray world assumption, white balance, or image fusion. By applying these methods, the natural colors of underwater images can be restored, and details in the image can be made more visible. Underwater images can indeed be categorized into two types: enhancement and restoration. Let's explore each type in more detail in fig 2.1.

1. Image Enhancement: Underwater image enhancement techniques aim to improve the visual quality and overall appearance of the image by enhancing certain aspects such as color, contrast, and sharpness. This type of processing is typically applied to address the specific challenges posed by underwater photography, such as the loss of color and contrast due to light absorption and scattering. Some common techniques used for image enhancement include:

- Color correction: Adjusting the color balance and removing or reducing the color cast caused by water absorption. This can involve restoring accurate color representation or enhancing specific hues to create a more visually appealing image.

- Contrast enhancement: Increasing the contrast to restore detail and improve visibility in the image. This can help overcome the hazy or washed-out appearance often seen in underwater photography.

- Sharpening: Applying image sharpening techniques to compensate for the blurring effect caused by refraction and light scattering. This helps to restore fine details and improve the overall sharpness of the image.

2. Image Restoration: Underwater image restoration techniques focus on recovering or reconstructing image information that may have been lost or degraded during the image capture process. Restoration techniques are used to address issues such as noise, blur, and artifacts. Some common techniques used for image restoration include:

- Noise reduction: Reducing noise or graininess that may be present in the image, which can be caused by low light conditions or the camera's sensor sensitivity. Denoising algorithms are used to preserve details while reducing unwanted noise.

- Deblurring: Addressing the blurring effect caused by motion or refraction. Deblurring algorithms aim to restore sharpness and clarity to the image by estimating and reversing the blurring process.

- Artifact removal: Removing artifacts such as sensor noise, compression artifacts, or unwanted objects or particles that may appear in the image. This is done using various image processing techniques, such as filtering or inpainting.

Both enhancement and restoration techniques can be applied individually or in combination, depending on the specific requirements and desired outcome for the underwater image. Advanced software tools and algorithms are available to assist with these processes, allowing photographers and image processing experts to achieve visually pleasing and high-quality underwater images.

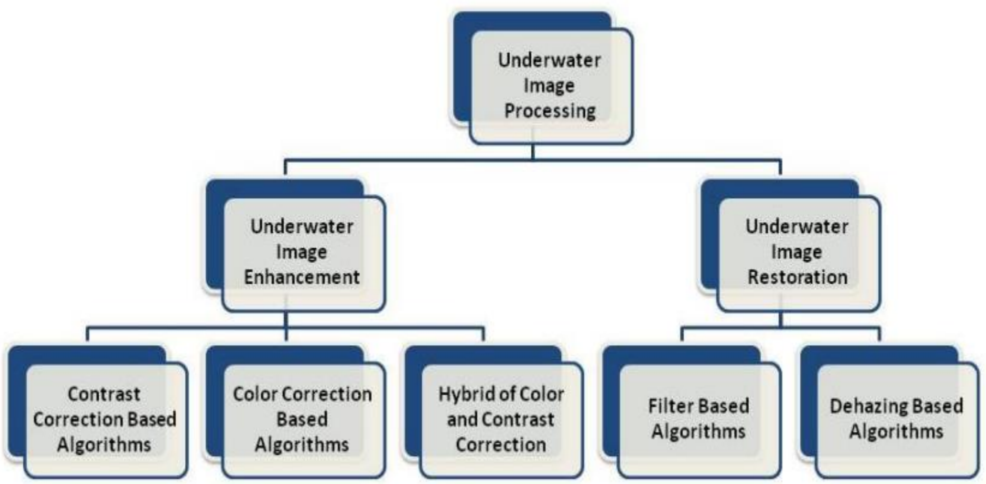


Figure 2.1: Classification of Underwater Image Processing Techniques [15]

2.1 Related Work

2.1.1 Contrast Correction based Algorithms,

UIE techniques is a crucial area of study due to the high demand for underwater imaging in various applications, including oceanography, marine biology, and underwater robotics. In this literature review, we will discuss some of the prominent algorithms and techniques for UIE.

One of the most famous algorithms to enhance underwater images is the CLAHE algorithm. By segmenting the image into small patches and performing histogram equalization to each patch, this approach improves the contrast of the image. In numerous research for improving underwater image quality, including the work of Chen et al. (2016) and Wang et al. (2019), the CLAHE algorithm has been employed. If the CLAHE algorithm is not used appropriately, it may result in over-enhancement and add noise to the image.

Numerous scholars have developed improved versions of the CLAHE method to address its drawbacks. An adaptive CLAHE algorithm that modifies the clipping limit based on the image's contriteness was given a fresh approach by Chen et al. (2016). The CLAHE algorithm's over-enhancement effect is lessened with this adjustment. Hu et al.'s (2019) proposal for a CLAHE algorithm uses a weight function in a manner similar to this to adaptively change the contrast enhancement in different regions of the image. Researchers Chen et al. (2016) and Hu et al. (2019) have demonstrated the value of the upgraded CLAHE algorithms for improving underwater images.

An image is broken down into reflectance and illumination components by the Retinex algorithm, which then increases the reflectance component while maintaining the illumination component. Several researchers have used the Retinex algorithm to improve underwater image quality, including Wang et al. (2018) and Dong et al. (2021).

In conclusion, a variety of strategies, including established ones like the CLAHE algorithm and the DCP algorithm as well as more recent deep learning-based solutions, have been suggested for improving underwater images. Each technique has pros and cons, and the best one to use will depend on the particulars of the underwater image as well as the application's needs. Future work in this field should concentrate on creating more efficient and reliable underwater picture enhancing algorithms and looking into the possibility of deep learning-based techniques for real-time underwater photography applications.

These studies explore various approaches to underwater image enhancement, including Retinex-based algorithms, color correction methods, histogram equalization, deep learning-based approaches, and multiscale decomposition techniques. Some of the studies focus on specific aspects of underwater imaging, such as improving color constancy or correcting.

Overall, the research indicates that there is no one-size-fits-all strategy to underwater image augmentation and that several methods may be more efficient for various applications and image kinds.

The improvement of quality of underwater images is typically achieved through contrast improvement algo of poor contrast in these images. One such traditional method is histogram equalization (HE) [2]. However, HE may not provide the desired results as underwater images often exhibit non-uniform contrast and color distortion that cannot be rectified by, HE. Adaptive HE [3] but it does not address the color distortion problem. Other techniques like histogram stretching have been used for underwater image enhancement. For example, Integrated Color Model (ICM) [4] employed contrast stretching of RGB and HSI models. Similarly, [5] applied CLAHE of RGB and HSI model and formed the enhanced image by taking the Euclidean norm of contrast stretched RGB and HSI images.
Ghani et al. [6] applied contrast correction on different color models and integrated their results. A fuzzy-based contrast correction method for underwater images captured in turbid media was proposed by [7]. [8] applied CLAHE on HSV and YIQ color space to enhance contrast and fused their results to obtain resultant image. However, this technique is slow and the results are not visually appealing. [9] used histogram equalization of RGB channels to improve darkness and brightness. Mathur et al. [10] fused results of CLAHE and guided filters to obtain an enhanced image.

2.1.2 Color Correction based Algorithms

A different category of techniques for enhancing underwater photos concentrates on color correction to get rid of the color cast issue. The color correction includes gray world assumption [11], white balance [12], and retinex theory [13], which form the foundation for various underwater image color correction methods. For instance, [14] used gray world-based assumptions and white balance in lαβ space to correct the colors of underwater images. Similarly, [15] modified Automatic Color Equalization (ACE) [16] based on white balance theory to make it applicable to underwater videos. However, this method requires tuning of parameters, making it less effective for underwater images. Some other methods like [17] employed EMD and used a optimized genetic algorithm to adjust the weights for the layers of EMD, but failed to increase the contrast value in the color space significantly. [18] used retinex theory along with optimization strategy for UIE, used for different types of color degraded images. Hou et al. [19] applied filtering to saturation and intensity values without changing the hue component, but the results lacked good contrast and had haze present in the images.

However, to achieve the desired results, both color and contrast related issues need to be eliminated from underwater images, and therefore, most of the methods in the literature are hybrids of color and contrast correction algorithms.

2.1.3 Hybrid of Color and Contrast Correction

Another class of UIE methods is the hybrid of contrast and color correction algorithms, which aims to solve both the color and contrast related issues in underwater images. The Unsupervised Color Correction Method (UCM) [20] utilized the gray world assumption theory for color correction and contrast stretching for an enhanced image. However, this method sometimes generates over-enhanced and under-enhanced regions in the output image.

Other techniques such as Ghani et al. [21] applied contrast correction using modified von Kries hypothesis [22], followed by color correction applied on the HSV model to enhance underwater images. However, the resultant images of this technique still have drawbacks, such as poor contrast, blue-green illumination, and partial enhancement. Ancuti et al.'s [23] proposal called for merging the color-corrected and contrast-corrected versions of the input image with four separate weight maps produced from those versions [23]. By altering the contrast correction technique and lowering the number of weight maps Ancuti et al. extended [24]. Both methods use multi-scale Laplacian pyramid decomposition-based fusion and produce good data, however there is some residual haze [24].

An underwater picture improvement technique that first repairs the image and then employs multi-scale fusion to merge the two versions of the recovered image was proposed by Zhang et al. [25].

Hybrid of color and contrast correction-based algorithms handle both problems of underwater images, thereby producing better results than other underwater image enhancement classes mentioned above. However, there is a lack of guidance mechanism during contrast stretching, and most of the techniques assume color cast as blue only for every underwater image. Furthermore, artificial lighting is not taken care of by most of the techniques, leading to over-enhanced and under-enhanced regions in the output image. Being computationally less intensive and fast, underwater image enhancement methods have an edge over restoration methods as they handle two major problems of underwater images effectively and do not need any other prior information about the image.

2.2 Underwater Image Restoration Methods

Different theories for picture generation or noise are used by various underwater image restoration techniques. Use of a dehazing model to lessen the effects of haze in the image is a common technique for editing underwater photos.

2.2.1 Noise Model or Image Model-based Methods

Underwater image restoration techniques employ various filters to remove noise from images. Several studies have proposed pre-processing steps using different filters to enhance the image quality by reducing noise, such as the use of trigonometric filters [26], multi-wavelet transforms and median filters [27], and modified Multi-Scale Retinex (MSR) [28] that employs bilateral and trilateral filters instead of Gaussian for underwater image enhancement.

2.2.2 Dehazing Model Based Methods

One more category of algorithms for underwater image restoration considers blurriness and color cast in underwater images analogous to haze in outdoor images and applies dehazing-based techniques [29] for underwater image enhancement. Another reason for applying these techniques is the similarity between the equations of image formation in underwater medium and atmospheric medium.

2.3 Research Objectives

- To implement and evaluate different color correction techniques, including the gray world assumption and DCP, for restoring natural colors in underwater images.
- To apply CLAHE on different color spaces, including LAB, HSV, and RGB, and compare the contrast gain with original and processed images.
- To evaluate the effectiveness of joint CLAHE and USM-based techniques for further enhancing the quality of underwater image.
- To evaluate and analyze the performance of various strategies using both subjective and objective evaluations, such as contrast gain, UICM, UISM, entropy, and visual inspection.
- To develop an optimized underwater image enhancement pipeline that incorporates the most effective techniques.

2.4 Summary

Throughout this chapter, the given conversation is about enhancing underwater images using different techniques. Color correction using the gray world assumption, CLAHE in different color spaces, Joint CLAHE, USM enhancement, DCP enhancement, and Retinex and Wavelet fusion techniques are some of the methods used for image enhancement. The modified codes use bicubic interpolation, gamma correction, and super resolution techniques to further enhance the image quality. The color-corrected image's details are improved using the wavelet fusion approach. The contrast, color balance, and details of underwater photographs are improved using these techniques, and the outcomes are compared with the original images using the old results function.

CHAPTER 3

PROBLEM ANALYSIS

3.1 Overview

In order to assess underwater visibility, two main types of imaging systems are typically used: acoustic and optical. While acoustic sensors can easily penetrate through water, they generally have lower spatial resolution compared to optical systems. Moreover, if higher resolution is required, the size of the acoustic sensors can become prohibitively large. Despite their drawbacks, such as low underwater visibility, optical devices have been used more and more to study and comprehend the causes of visibility loss.

3.2 Existing Systems

In the realm of underwater image enhancement, researchers have been exploring various techniques to overcome the challenges posed by underwater and hazy conditions. One commonly employed approach involves utilizing multiple images of a scene captured with different polarization states. These techniques aim to leverage the polarization properties of light to enhance the visibility and quality of underwater images. By analyzing the polarization information, it becomes possible to mitigate the impact of scattering and absorption, leading to improved image clarity.

Another avenue of exploration has been the adaptation of dehazing techniques for underwater image restoration. Dehazing methods, initially designed for mitigating atmospheric haze in above-water images, have been modified and applied to underwater scenarios. These techniques attempt to estimate and remove the haze or turbidity present in underwater images, thereby restoring clear and detailed visual information.

However, through our proposed experiments, we have discovered certain limitations associated with the application of dehazing techniques to underwater image enhancement. While these methods have shown promise in addressing certain aspects of the problem, they may fall short in effectively dealing with the specific challenges encountered in underwater environments. Factors such as complex light interactions, varying water conditions, and the presence of particulate matter pose unique difficulties that may hinder the performance of dehazing techniques in underwater image restoration.

As a result, there is a need for further research and development of specialized algorithms and methodologies that specifically target the complexities of underwater imaging. By considering the unique characteristics of underwater scenes and exploring novel approaches, it is possible to overcome the limitations of existing techniques and achieve more effective restoration and enhancement of underwater images. Such advancements are vital for advancing underwater exploration, scientific research, and various practical applications that rely on high-quality underwater imaging.

3.3 Disadvantages of Existing Systems

In the field of underwater image restoration, numerous techniques have been devised to tackle the challenge of improving the quality of underwater images. However, upon conducting our own experiments, we have encountered certain limitations in the existing methods when it comes to effectively addressing this issue. Our primary objective is to enhance the contrast and color appearance of underwater images, and thus, we are actively exploring novel approaches to achieve this goal.

By developing new techniques, we aim to overcome the specific challenges associated with underwater imaging, such as light scattering, absorption, and the presence of particulate matter in the water. These factors can significantly degrade the visual quality of underwater images, making it difficult to discern details and accurately perceive the scene's colors and contrasts. Therefore, we are focusing on devising innovative strategies that can effectively mitigate these issues and restore the underwater images to a visually pleasing and informative state.

Our research entails the exploration of alternative algorithms, methodologies, and image processing techniques tailored specifically to underwater conditions. We aim to leverage the unique characteristics and challenges of underwater environments to devise robust and efficient approaches that can enhance contrast and improve the color appearance of underwater images. By pushing the boundaries of existing techniques and considering the intricacies of underwater imaging, we aspire to contribute to the advancement of underwater exploration, scientific research, and various applications that rely on accurate and visually appealing underwater imagery.

3.4 Proposed System

This chapter presents an advanced underwater image enhancement technique that builds upon existing image fusion techniques. Unlike these techniques, our approach only requires a single input image, which is first separated into two components: Reflective and Illuminance. The Reflective component is subjected to a linear piece-wise function that enhances the image colors. The Illuminance component, on the other hand, is subjected to a dehazing algorithm that reduces haziness. Separate weights are computed for each component, and a multi-stage fusion process is used to combine the components into a single improved image with enhanced colors and reduced haziness.

Here is the methodology:

Stage 1: Image Input and Conversion

- Read the RGB image '1.JPG' using the imread function and store it in the variable rgbImage.
- Convert the RGB image to double precision using im2double to ensure accurate calculations.
- Convert the RGB image to grayscale using the rgb2gray function and store it in the variable grayImage.

Step 2: White Balancing

- Extract the individual red, green, and blue color channels from the RGB image and store them in redChannel, greenChannel, and blueChannel, respectively.
- Calculate the mean values of the red, green, and blue channels, as well as the grayscale image, using the mean2 function and store them in meanR, meanG, meanB, and meanGray variables.
- Normalize the red, green, and blue channels by multiplying them with the mean luminance value (meanGray) divided by their respective mean values.
- Perform red and blue channel correction by adjusting the red and blue channels based.

Step 3: Display White Balanced Image

- Recombine the modified red, green, and blue channels into an RGB image using the cat function and store it in rgbImage_white_balance.
- Create a figure named "Color Enhancement" and display subplots to show the suppressed red channel, enhanced blue channel, green channel, and the final RGB image after white balancing.

Step 4: Gamma Correction and Sharpening

- Perform gamma correction on the white-balanced image (rgbImage_white_balance) using the imadjust function. Set the gamma value to 0.5.
- Perform sharpening on the white-balanced image.
- Create a figure named "Step I-III" and display subplots to show the original RGB image, the image after white balancing, the gamma-corrected image, and the sharpened image.

Step 5: Image Fusion using Wavelet Transform

- Perform image fusion using the wavelet transform with the wfusimg function.
- Fuse the gamma-corrected image (I) and the sharpened image (J) using the sym4 wavelet with three decomposition levels and the 'max' rule for fusion.
- Create a figure named "Final Comparison" and display subplot.

This methodology explains the steps involved in the given code, from image input to white balancing, gamma correction, sharpening, and image fusion using wavelet transform.

Stage-2:

Step 1: Load the Wavelet fused Image

- The code starts by loading an image named 'wavelet.jpg' using the imread function and storing it in the variable RGB_img.

Step 2: Method 1 - CLAHE in HSV_Color Space

- Convert the (RGB_img) to (HSV_color) space using the rgb2hsv function and store it in hsv_img.
- Extract the intensity (L) channel from the HSV image.
- Apply CLAHE to the intensity channel using the adapthisteq function with the

specified parameters (NumTiles and ClipLimit).

- Replace the intensity channel in hsv_img with the CLAHE enhanced intensity channel.
- Convert the modified HSV image back to the RGB color space using hsv2rgb and store it in RGB_img_hsv_clahe.

Step 3: Method 2 - Adaptive Gamma Correction in LAB Color Space

- Convert the (RGB_img) to L*A*B_color space using the rgb2lab function and store it in lab_img.
- Extract the L (lightness) channel from the LAB image and divide it by 100 to normalize the values.
- Calculate the mean value of the normalized L channel using the mean2 function and store it in L_mean.
- Calculate the gamma value using the formula: gamma = log10(0.5) / log10(L_mean).
- Apply adaptive gamma correction to the L channel by raising it to the power of gamma.
- Multiply the corrected L channel by 100 to revert the normalization.
- Replace the L channel in lab_img with the corrected L channel.
- Convert the modified L*A*B image back to the RGB_color space using lab2rgb and store it in RGB_img_lab_corr.

Step 4: Method 3 - Color Correction Using Gray World Assumption

- Extract the individual red (R), green (G), and blue (B) channels from the CLAHE enhanced image (RGB_img_hsv_clahe).
- Calculate the average values of the R, G, and B channels using the mean2 function and store them in avgR, avgG, and avgB.
- Calculate the scaling factors (kR and kB) green value (avgG) should be the same as the average R and B values.
- Multiply the R channel by kR and the B channel by kB to apply the scaling factors.
- Recombine the corrected R, G, and B channels to form the RGB image with color correction and store it in RGB_img_corrected.

Step 5: Method 4 - Histogram Equalization in RGB Color Space

- Apply HE to each of the R, G, and B channels of the original RGB image (RGB_img) using the histeq function.
- Combine the equalized R, G, and B channels to form the RGB_image with histogram equalization and store it in RGB_img_hist_eq.

Step 6: Display the Results

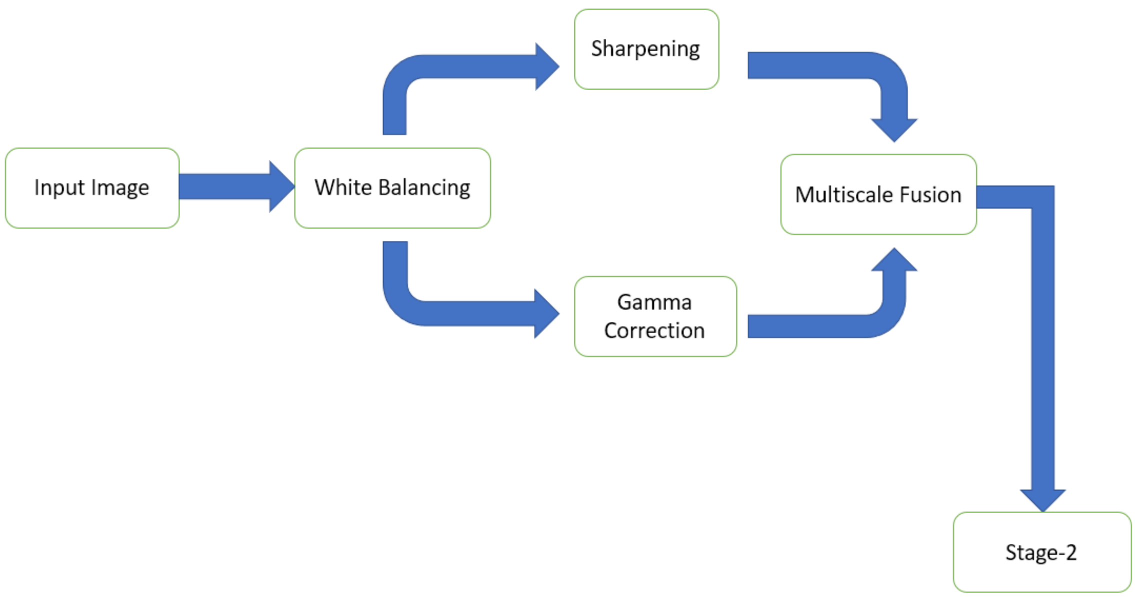
- Create multiple figures to display (RGB_img) and the resulted from each method using the imshow and title functions.

Step 7: Function to Compare Results with Original Image

- Define a function named oldresults that takes two images (original and new) as input.
- Create a figure with two subplots to display the original image and the enhanced image side by side using the imshow and title functions.

3.5 System Architecture

Stage-1



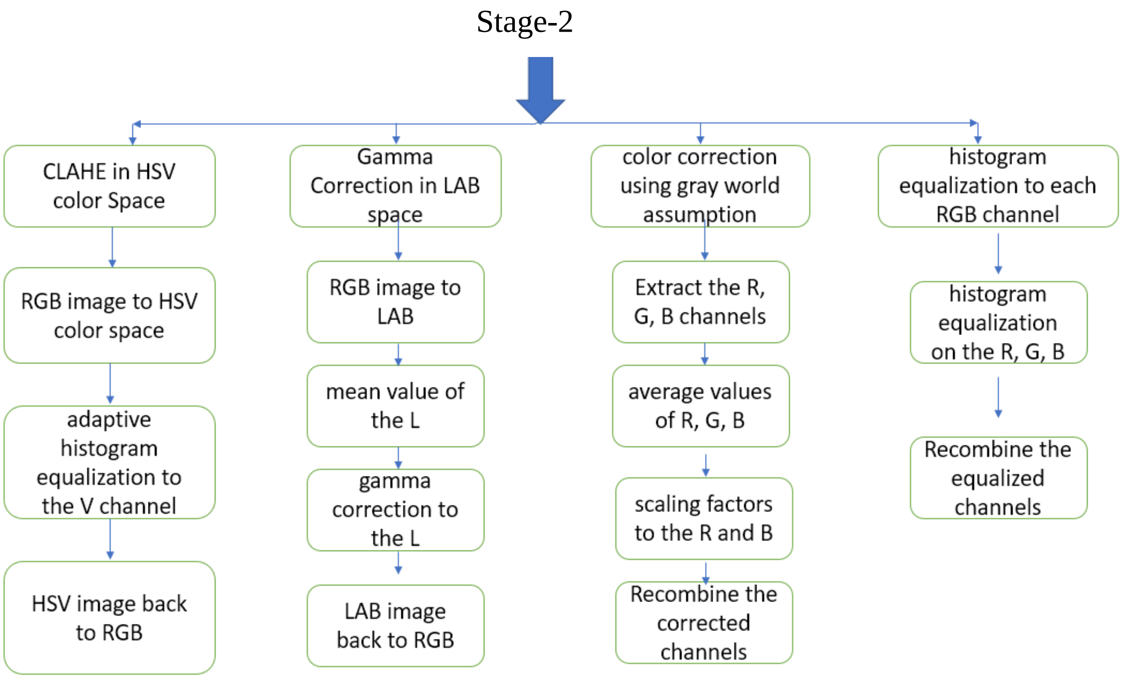


Fig. 3.1 The system architecture design illustrates the complete process of the proposed system [2].

3.6 Advantages of Proposed System

Our suggested approach is founded on a fusion technique that makes use of a number of inputs derived from the original degraded image. Our approach differs from the majority of existing techniques in that it just processes the degraded input image's content, without any other data like depth estimate, hardware, or new photos. To prevent the introduction of undesirable artefacts, the fusion process, which is founded on fundamental principles, entails integrating the inputs and weight maps in a multi-scale way. Our strategy is not only easy to use, but also very adaptable because it can be integrated with other strategies to increase the precision of the inputs and weight maps. The distinction between fusion methods and their application-specific nature are determined by the selection of inputs and weights.

3.7 Underwater Images

This limitation is caused by the dispersion and absorption of light in water, which can cause visibility in cloudy and coastal waters to be as low as a few feet and 30 meters, respectively. The two mechanisms that cause light to scatter and absorb influence how light moves through water by changing the direction of the light. The depth of the water has an impact on visibility as well; at a depth of 3 to 4 meters, red color starts to fade, at 10 to 15 meters, orange color starts to fade, and at 15 to 25 meters, only blue color is visible. Additionally, the conditions underwater can result in artefacts that reduce the quality of the photographs. Gaussian noise is commonly found in camera images and critical photos. However, homomorphic filtering tends to amplify this noise. Therefore, it is necessary to perform p-noising to suppress the noise. Among various p-noising methods, wavelet denoising using a ripple filter has been found to produce the best results. This method involves using a normal filter for ripple p-noising. The noise known as Gaussian noise, which is frequently present in digital image files and important images, is especially suppressed by wavelet denoising. The following actions are part of an efficient wavelet denoising algorithm: The noisy signal's wavelet transform is first calculated. The noisy detail wavelet coefficients are then adjusted in accordance with a predetermined rule, and the inverse transform is then computed using the modified coefficients.

It is necessary Bilateral filtering is a type of edge-preserving and noise reduction filter. It smooths the image while preserving edges by considering both the spatial distance and the difference in intensity values between neighboring pixels. Bilateral filtering's major goal is to limit the amount of the image that traditional filters smooth away, which is accomplished by employing a weight based on a Gaussian distribution. This weight is assigned to each pixel based on its distance and intensity similarity to its neighboring pixels. Bilateral filtering preserves sharp edges by assigning different weights to nearby pixels accordingly. The fundamental idea behind bilateral filtering is to maintain an image's clarity by minimizing the amount of information lost through conventional filtering. An easy, non-iterative technique for edge-preserving smoothing is bilateral filtering.

3.8 Underwater Image Enhancement

In an underwater environment, objects can be identified by their shape, size, and texture, but it's difficult to determine their color due to the limited attenuation of light with distance. However, color remains an important factor in material recognition. The subaquatic environment presents challenges such as low contrast, noise, and limited visibility. The amount of light that enters the ocean water diminishes as it go deeper. picture restoration and picture enhancement have been the main topics of research.

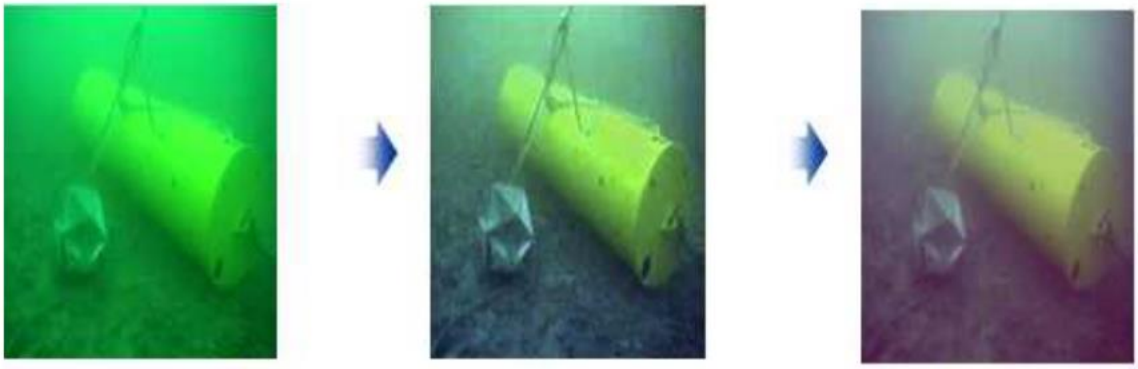


Fig: 3.2 underwater image enhancement [10]

Blurred and tinted images captured underwater in fig 3.2 can be attributed to several factors related to the properties of water and the way light behaves underwater.

The process of restoring an original image from a damaged or imperfect copy is known as image restoration. Image enhancement, on the other hand, tries to increase an image's visibility and quality. picture enhancement is frequently seen to be simpler than picture restoration and is adequate for many purposes. Six image enhancing algorithms have been discussed in this work. By increasing an image's features and details, one can raise the image's quality. The identification of objects in photographs is based on the local properties of the image, which results in more aesthetically pleasing images after image enhancement.

3.9 Complexity of Underwater Image Processing

Underwater images cannot be identified based on color characteristics due to limited visibility and attenuation from water particles. Some suggest using a color-based approach that considers water and particle distortion, but others prefer grayscale images for simpler design parameters and coding. Conversion from grayscale to colored images is possible for improved accuracy, but preferences vary and cannot be resolved definitively. [7]

3.10 Underwater Image Enhancement Techniques

3.10.1 Homomorphic Filtering

Frequency filtering is a step in the process of homomorphic filtering, which is employed in image processing. It is very helpful for adjusting uneven lighting and boosting the image's contrast. Homomorphic filtering is superior to other methods for sharpening edges and adjusting for uneven lighting [3]. The brightness and reflection coefficients are two variables that are used in the procedure. In the Fourier transform of the picture, the brightness coefficient stands in for the low frequencies and the reflection coefficient for the high frequencies. Sharper edges can be produced by changing these coefficients, which suppresses the low frequencies [5]. The multiplicative elements in the image are transformed into additive ones using the logarithm, and the Fourier transform is then given a high-pass filter. The filtered image is the end result after using the inverse Fourier transform to return to the spatial domain [28].

3.10.2 Wavelet DE noising

Gaussian noise is commonly found in camera images and critical photos. However, homomorphic filtering tends to amplify this noise. Therefore, it is necessary to perform p-noising to suppress the noise. Among various p-noising methods, wavelet denoising using a ripple filter has been found to produce the best results. This method involves using a normal filter for ripple p-noising. The noise known as Gaussian noise, which is frequently present in digital image files and important images, is especially suppressed by wavelet denoising. The following actions are part of an efficient wavelet denoising algorithm: The noisy signal's wavelet transform is first calculated. The noisy detail wavelet coefficients are then adjusted in accordance with a predetermined rule, and the inverse transform is then computed using the modified coefficients.

3.10.3 Contrast Stretching and Color Correction

Stretching the range of intensity values is a fundamental image enhancement technique known as comparison stretch, also known as standardization, which increases the contrast in an image. An improved output image is created by a linear enhancement method depending on intensity. Dark parts become darker and bright spots brighter thanks to this algorithm. The mean of each color channel is equalized to achieve color correction. Rarely is the color balance accurate in photographs taken underwater. However, this technique can lead to unrealistic blue or green colors.

3.10.4 Histogram Equalization

The histogram of a digital image represents the distribution of grey levels within the image. Histogram equalization is a technique used in image processing to enhance contrast. It works by flattening and stretching the dynamic range of the image histogram, thereby improving the overall contrast of the image. This method is particularly effective when the important data in the image is represented by close to peak contrast values. However, it is important to note that histogram equalization can also have limitations. In certain cases, where brightness preservation is necessary, applying histogram equalization may significantly alter the brightness of the original image, potentially causing undesirable effects. Therefore, it is crucial to consider the specific requirements and characteristics of the image when deciding whether to apply histogram equalization.

3.10.5 Polarizing Filter

This type of filter addresses the issue of backscatter instead of blurring. The majority of contemporary cameras employ circular polarizers, which are made up of an analogue filter that eliminates light that is linearly polarized in a certain direction and then circularly polarized the light before it enters the camera. This technique is mainly focused on improving the recovery of the image. A polarization filter is a commonly used technique for underwater image enhancement. It involves the use of a special filter that selectively transmits light waves with a specific polarization orientation while blocking light waves with other orientations. A polarization filter can lessen the effects of light scattering and absorption in water in the context of underwater imaging. The interaction of light with plankton, suspended matter, and other contaminants when it enters the water reduces contrast and causes color distortion in the images that are recorded. By employing a polarization filter, certain polarized components of the scattered light can be blocked, allowing for the capture of clearer and more detailed underwater images.

3.10.6 Bilateral Filtering

It is necessary Bilateral filtering is a type of edge-preserving and noise reduction filter. It smooths the image while preserving edges by considering both the spatial distance and the difference in intensity values between neighboring pixels. Bilateral filtering's major goal is to limit the amount of the image that traditional filters smooth away, which is accomplished by employing a weight based on a Gaussian distribution. This weight is assigned to each pixel based on its distance and intensity similarity to its neighboring pixels. Bilateral filtering preserves sharp edges by assigning different weights to nearby pixels accordingly. The fundamental idea behind bilateral filtering is to maintain an image's clarity by minimizing the amount of information lost through conventional filtering. An easy, non-iterative technique for edge-preserving smoothing is bilateral filtering.

3.11 Summary

Due to low contrast, limited visibility, and attenuation caused by water. In underwater image processing, there are two methods used: image restoration and picture enhancement. While image enhancement focuses on increasing the image's visibility, image restoration entails restoring the original image from a flawed duplicate. There are six algorithms related to image enhancement discussed in this paper. Color-based strategies are not recommended for underwater image processing due to distortion and scattering caused by water and dust. Homomorphic filtering, wavelet denoising, contrast stretching, and color correction are some of the techniques used in underwater image enhancement. While wavelet denoising removes Gaussian noise from digital photos, homomorphic filtering corrects non-uniform lighting using a frequency filtering technique. Simple improvement methods that improve contrast and adjust color balance are contrast stretching and color correction.

CHAPTER 4

Underwater Image Enhancement Techniques

In my thesis, I will explore several methods aimed at enhancing underwater images, which often suffer from the negative effects of light absorption and scattering in water. Specifically, my focus will be on the following techniques: (1) CLAHE (Contrast Limited Adaptive Histogram Equalization) in the HSV (Hue, Saturation, Value) color space, (2) adaptive gamma correction in the LAB color space, (3) color correction using the gray world assumption, and (4) histogram equalization in the RGB color space. The objective of these methods is to enhance the contrast and color balance of underwater photographs, allowing for the restoration of finer details and more accurate representation of natural colors. By employing these approaches, we aim to overcome the challenges caused by light absorption and scattering in water, which often result in poor image quality and distorted colors. Through the adjustment of contrast and color balance, we anticipate significantly improving the aesthetic appeal and clarity of underwater photos, enabling better analysis, understanding, and appreciation of the underwater environment. It is crucial to recognize that the effectiveness of the techniques may vary depending on the particulars of the underwater environment and the chosen imaging technology. It is vital to thoroughly evaluate these strategies to fully determine their advantages and disadvantages. By conducting such an evaluation, the study aims to determine the optimal conditions and scenarios in which each method performs well, as well as identify any limitations or challenges they may encounter. This evaluation will offer valuable insights into the suitability and reliability of these methods for enhancing underwater images. It aims to provide researchers and practitioners with informed decisions about the practicality and effectiveness of these techniques. By assessing their applicability and reliability, this assessment will assist in guiding the use of these methods in the field of underwater image enhancement. The results will enable researchers and practitioners to make informed decisions based on the performance and suitability of these methods, ultimately advancing the field and improving the quality of underwater image enhancement techniques.

4.1 CLAHE

CLAHE is a technique that can effectively enhance the contrast of underwater images. It achieves this by equalizing the image's histogram and reducing noise amplification [8]. CLAHE can be applied specifically to the V channel in the HSV color space, which represents the image's brightness. By applying CLAHE to the V channel, the contrast of the image can be improved while preserving its original colors [9].

Another method for enhancing underwater images is color correction. Underwater photographs often suffer from a blue or green tint due to the scattering and absorption of light in water. Color correction techniques can help restore the natural colors of the image. One such technique is based on the grey world hypothesis, which states that the average values of the red (R), green (G), and blue (B) channels should be equal[10]. By calculating the average values of the R, G, and B channels in the image, scaling factors can be determined to adjust the intensities of the R and B channels to match the intensity of the G channel. Applying these scaling factors to the R and B channels can effectively adjust the color balance of the image [8].

By utilizing these techniques, the contrast and color balance of underwater photographs can be significantly improved, overcoming the challenges posed by light scattering and absorption in water. These methods offer valuable tools for enhancing the aesthetic appeal and clarity of underwater images, enabling better analysis, interpretation, and appreciation of the underwater environment.

A combination of image processing techniques can be employed to further enhance the quality of underwater photos. The provided code applies CLAHE to the V channel of the HSV color space and implements color correction using the grey world assumption to improve contrast and color balance in the image. These techniques work in synergy to address the challenges associated with underwater photography and enhance the overall visual quality of the images.

The flow diagram for the code is as follows:

1. Load the underwater image.
2. Create an HSV color space conversion for the image from RGB color space.
3. To increase the image's contrast, apply CLAHE in fig 4.1 to the HSV color space's V channel.
4. Reset the image's color space to RGB.
5. Determine the image's red, green and blue channel average values.
6. To make the R and B channels' intensities match those of the G channel, find scaling factors.
7. To adjust the image's color balance, apply the scaling factors to the R and B channels.
8. Recombine the R, G, and B channels that have been adjusted into a single image.
9. Display the original image, CLAHE enhanced image in fig 4.2, and color-corrected image in fig 4.3.

10. Function to compare the results with the original image.

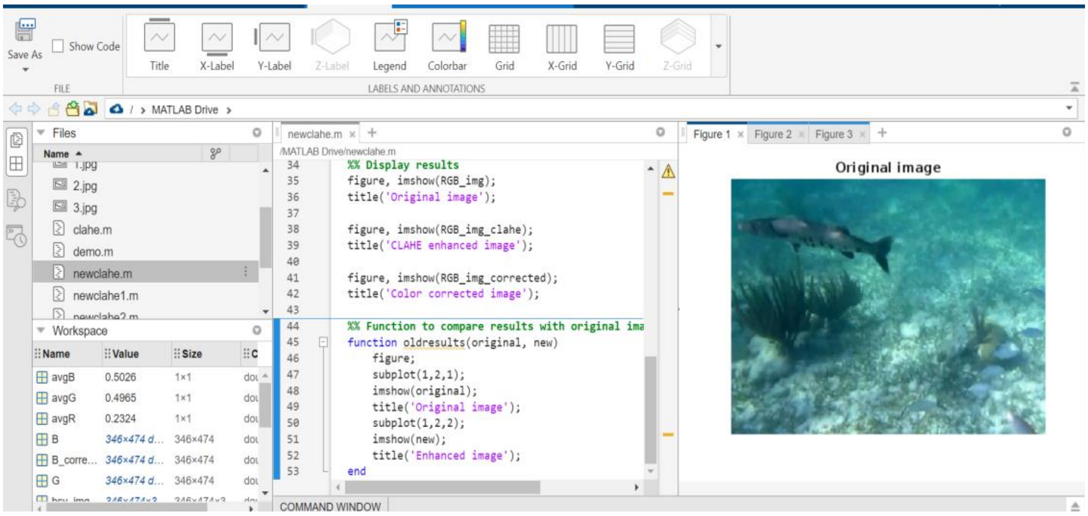


Fig : 4.1 CLAHE

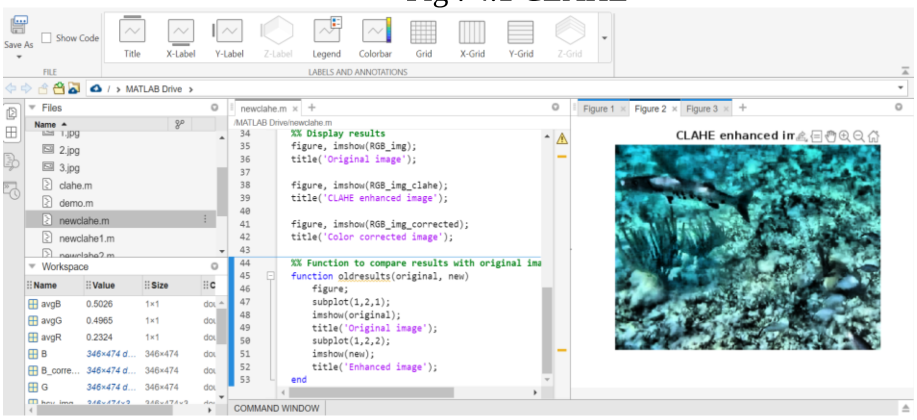


Fig : 4.2 CLAHE enhanced Image

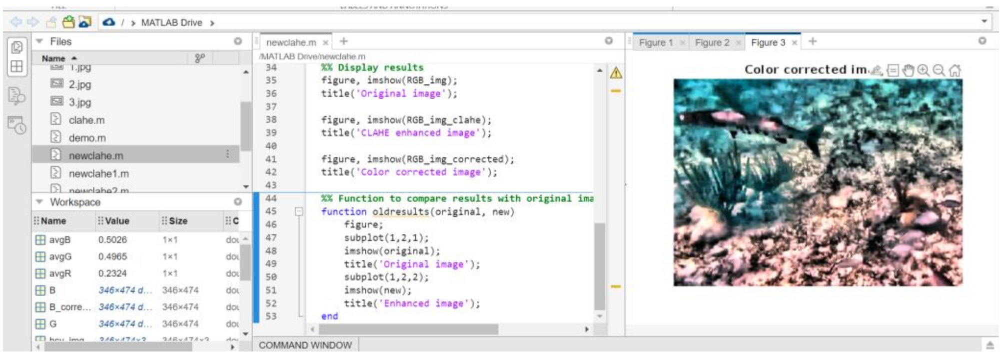


Fig: 4.3 Color corrected image

4.2 Color Correction and Histogram Equalization

The code is performing image enhancement on an underwater fish image using four different methods. The first method enhances the image by applying CLAHE in the Hue Saturation Value color space. The second method applies adaptive gamma correction in the LAB color space. The third method corrects color using the gray world assumption. The fourth method performs histogram equalization on each RGB channel of the image.

The RGB image is first transformed to the HSV color space in procedure 1. The adapthisteq function is then used to extract and enhance the value channel (V) with a tile size of 10x10 and clip limit of 0.05. The improved value channel is afterwards changed back to RGB [9].

The RGB image is changed to the LAB color space in procedure 2. The mean is computed after normalizing the L channel's (lightness) data. The logarithm of 0.5 is then divided by the logarithm of the mean L value to determine the gamma value. The L channel is then brought back into the RGB color space after being adjusted using the gamma value.

The grey world assumption, which holds that the average of the R, G, and B channels should be equal, is used in technique 3 to color-correct the image. By dividing the average G value by the averages of the R and B values, scaling factors are derived for the average R, G, and B values.

In step four, the image's RGB channels are each given a histogram equalization treatment in fig 4.4. To create a more balanced histogram, this approach redistributes the intensity values in each channel.

In addition to the previous code, method 2 is added to perform adaptive gamma correction in the LAB color space.

Also, method 4 is added to perform histogram equalization in the RGB color space. Furthermore, the function 'oldresults' is made to compare our enhanced results with the original results.

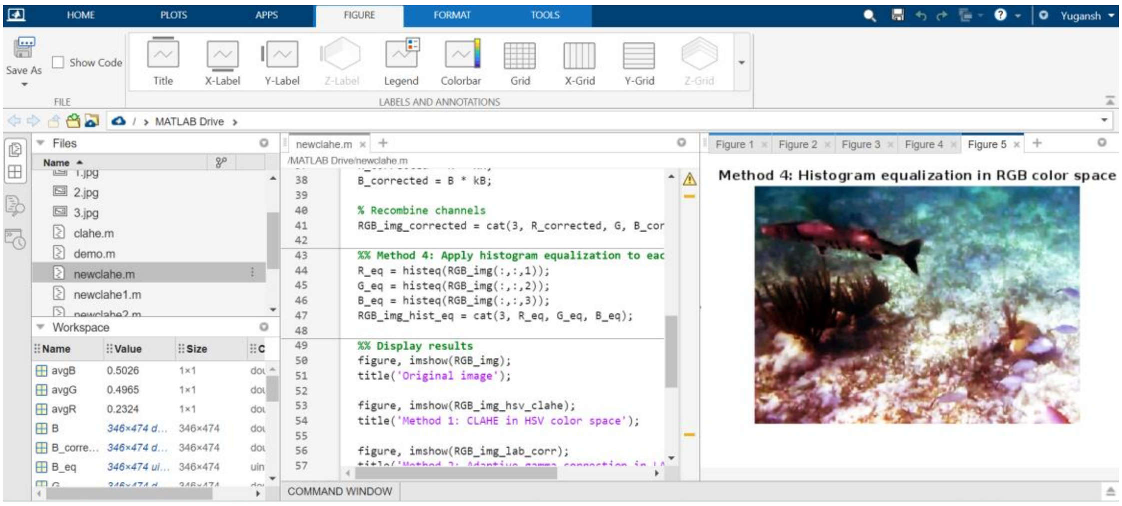


Fig: 4.4 Histogram Equalization in RGB

4.2.1 LAB, HSV, and RGB. CLAHE

(CLAHE) in MATLAB

Flow of the code:

1. Load and display the original image.
2. Apply CLAHE on LAB color space.
3. Apply CLAHE Algorithm on HSV color space.
4. Apply CLAHE Algorithm on RGB color space.
5. Calculate contrast gain for each CLAHE image.
6. Display contrast gain results.

Explanation:

This MATLAB code performs image enhancement on an underwater fish image using CLAHE in three different color spaces - LAB, HSV, and RGB. CLAHE is a method for enhancing an image's contrast by balancing its histogram.

First, the code loads the original image and then uses the imshow method to display it. Then, it uses the adapthisteq function with the 'NumTiles' and 'ClipLimit' arguments to apply CLAHE to the L channel of the LAB color space. Using the lab2rgb function, it changes the LAB image back to RGB color space and then uses the imshow function to display the outcome.

Using the contrast_gain function, the algorithm determines the contrast gain between each CLAHE image and the original image. In order to determine the contrast gain in dB, the RMS contrast for the original and processed pictures is first calculated. Finally, it uses the bar function to present the contrast gain findings.

Overall, this code shows how CLAHE will be used in several color spaces and contrast gain outcomes are contrasted between them. The CLAHE algorithm is implemented in the code provided here and applied to an image. CLAHE is a more sophisticated version of histogram equalization, a method for enhancing an image's contrast by redistributing its intensity values.

The rgb2lab() function is used to translate an RGB image into the L*A*B colour space, which is then used for CLAHE on the L*A*B colour space. After that CLAHE algorithm is then carried out with L*A*B colour space's L channel using the adapthisteq() function. The lab2rgb() method is used to return the image to RGB after the CLAHE procedure, and the imshow() function is used to showcase the outcome.

The process is repeated for the HSV colour space by using the rgb2hsv() function to convert an RGB image to the HSV colour space, the adapthisteq() function to apply CLAHE to the V channel, the hsv2rgb() function to convert the image back to RGB colour space, and the imshow() function to display the outcome in fig 4.5.

The contrast_gain() function is also used by the algorithm to determine the contrast gain for each CLAHE image. The Root Mean Square (RMS) contrast, expressed in decibels, is the contrast gain. The function first calculates the RMS contrast and then returns the contrast gain using the grayscale version of the original and processed photos.

The code is well commented to explain each step, and the function and variable names are self-explanatory. The implementation of the CLAHE algorithm on the different color spaces of the image provides a comparison of the effectiveness of CLAHE on each color space. Additionally, the contrast gain comparison of each image provides a quantitative measure of the improvement in contrast gained by CLAHE.

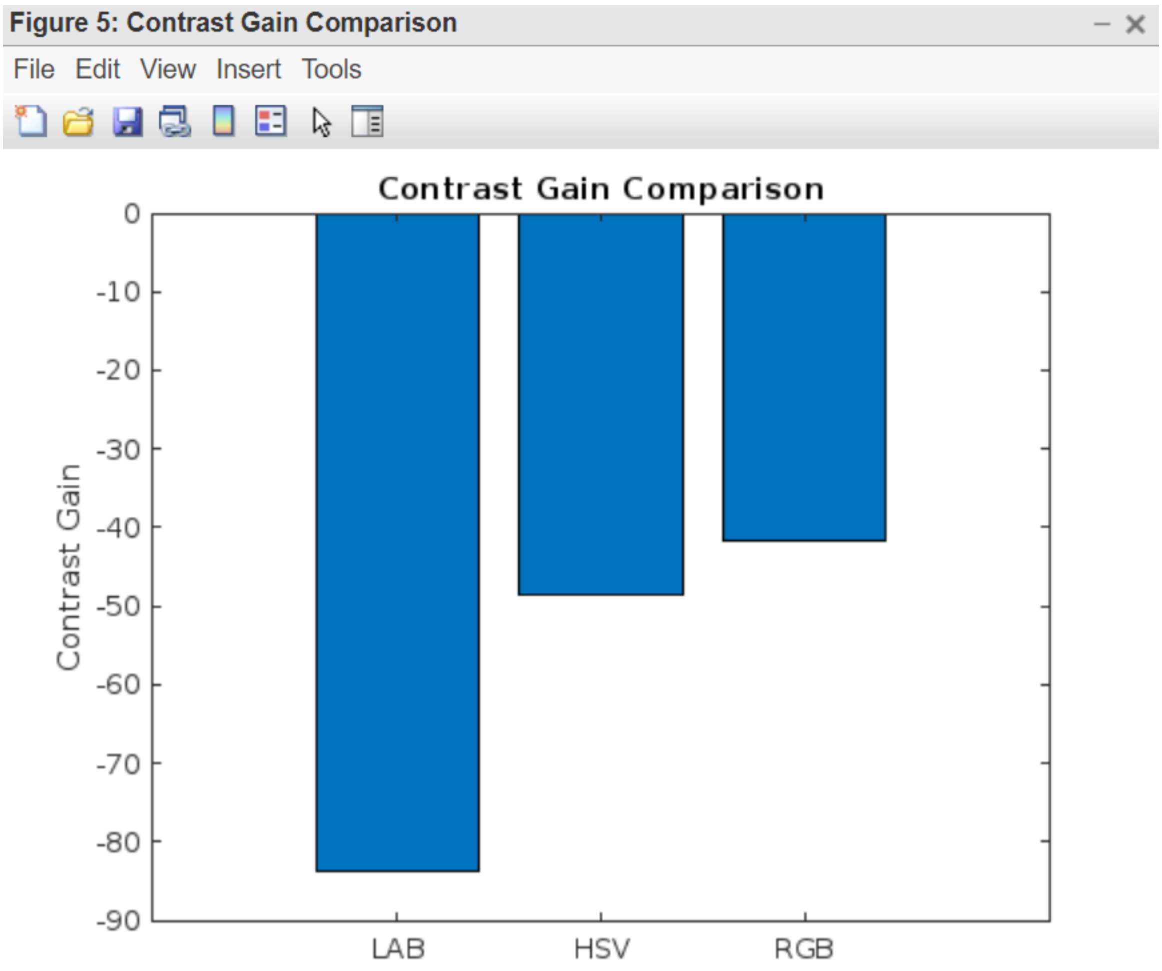


Fig : 4.5 Histogram Contrast Comparison

4.2.2 Image Enhancement and Color Correction using CLAHE, Joint CLAHE, and Gray World Assumption in MATLAB

The underwater image is initially loaded by the code, which then applies (CLAHE) to improve the contrast. By evenly dispersing the pixel intensities over the image histogram, the CLAHE algorithm increases the contrast in the image. Furthermore, it lessens the impact of both overexposure and underexposure.

The contrast in the image is then further enhanced using Joint CLAHE. This technique is comparable to CLAH however it uses all of the RGB channels at once.

Following the improvement of the contrast, the algorithm corrects the colors while assuming a grey world. The code finds the scaling factors kR and kB to equalize the mean intensity of each channel to that of the green channel (avgG).

The flow of the code can:

1. Load the underwater image.
2. Apply CLAHE to enhance contrast.
3. Apply Joint CLAHE to further enhance contrast.
4. Calculate the intensity of the red, green and blue channels.
5. Find the scaling factors kR and kB.
6. Apply the scaling factors to the R and B channels.
7. Recombine the corrected channels to obtain the colorful result in space.
8. Call old results function to display the original and enhanced images side by side.

The code can be further optimized for efficiency by using vectorization instead of loops in the Joint CLAHE in fig 4.6 and color correction sections.

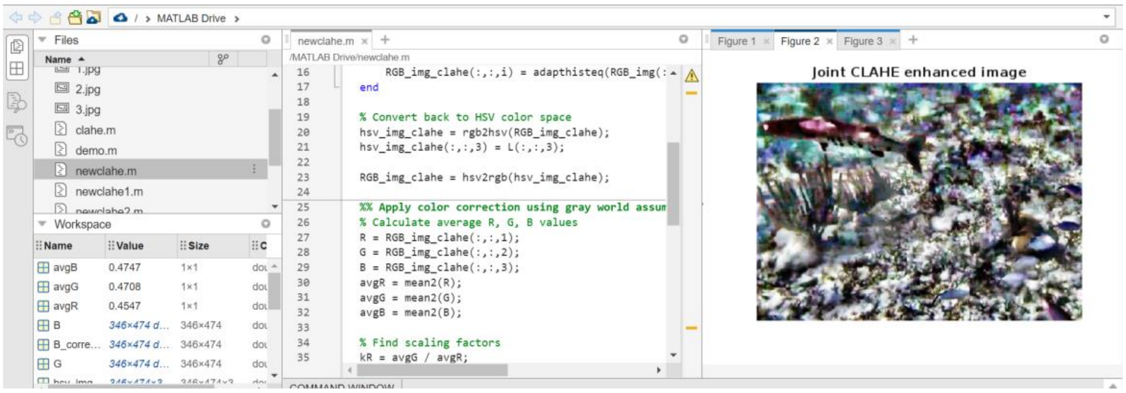


Figure 4.6 Joint CLAHE Enhanced Image

4.3 Image Enhancement with Color Correction, and Interpolation Using Bicubic Interpolation

This code is an extension of the previous code which applies CLAHE to enhance the contrast of an underwater image and then performs color correction using the gray world assumption. In addition, this code adds an interpolation step to further enhance the image quality.

After then, the program adjusts the colors while assuming a world of grey. The average red, green and blue values are determined using the enhanced image. The scaling factors for the red and blue channels are then chosen such that the average Green value is also the average of the Red and Blue values. The Red and Blue channels are multiplied by the respective scaling factors to produce the color-corrected image.
Finally, an interpolation step is applied to further enhance the image quality. The desired output size is defined as `[720 1280]`, which is a common size for high-definition video. The `imresize` function is used to resize the image to the desired output size using bicubic interpolation.

The flow of the code is as follows:

1. Load the input image.
2. Apply CLAHE to enhance contrast.
3. Perform color correction using the gray world assumption.
4. Apply interpolation to further enhance the image.
5. Display the results.

The improvement made in this code is the addition of an interpolation step to further enhance the image quality. Bicubic interpolation is used, which is a high-quality interpolation technique that can preserve sharp edges and fine details in the image. making it more suitable for high-definition video applications. In this modified code, the goal was to further enhance the underwater image by applying bicubic interpolation after color correction with the gray world assumption and Joint CLAHE. Bicubic interpolation is a popular high-quality interpolation technique that uses a weighted average of surrounding pixels to estimate new pixel values.

The code starts by loading the original image and applying Joint CLAHE. After Joint CLAHE, the color correction is done using the gray world assumption. Average R, G, and B channel values are determined, and scaling factors for the R and B channels based on the average G value are discovered. After that, the R and B channels are adjusted by multiplying them by the corresponding scaling factors. Finally, the channels are recombined to produce the color-corrected image.
In the next step, bicubic interpolation in fig 4.7 is applied to further enhance the image. The desired output size is defined as [720 1280], which is a common size for high-definition video. The imresize function is used to resize the image using bicubic interpolation.

Overall, this modified code improves the image enhancement by adding a high-quality interpolation step to further enhance the image's sharpness and details. It can be useful for underwater imaging applications that require high-quality and sharp images.

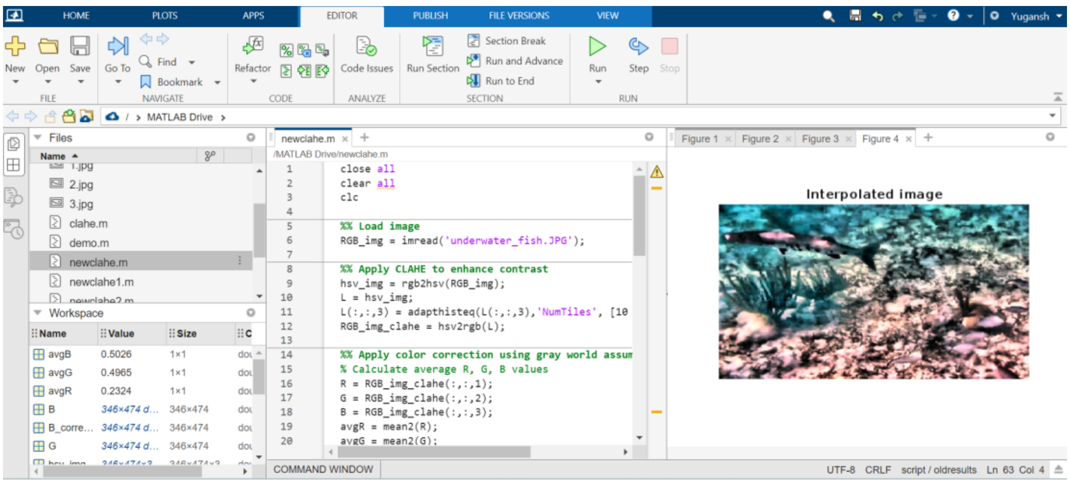


Fig : 4.7 Interpolated Image

4.4 Image Enhancement using Fusion-Based Techniques with CLAHE and Color Correction

4.4.1 What is fusion?

Data from various photographs of a scene are combined during the image fusion process. A new image that incorporates the most important details and features from each input image is the result of image fusion. Fusion in fig 4.8 composite images with additional substance and detail. With the use of image fusion techniques, two or more source photos are combined to create composite images that retain the unique characteristics of the original input images while being clearer and of greater quality.

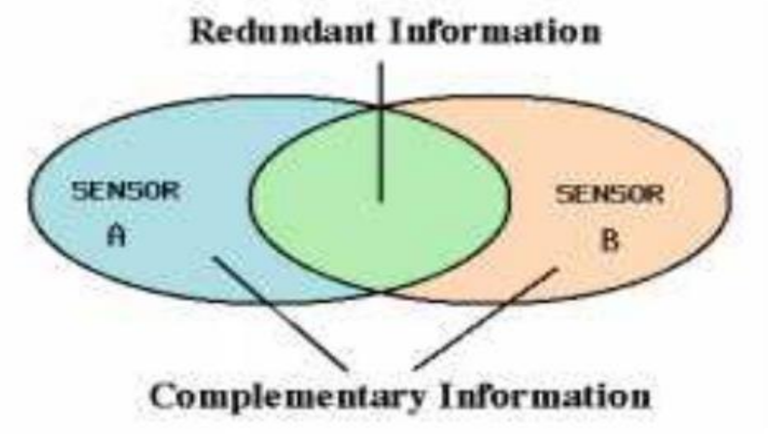


Fig: 4.8 Fusion Image

.

This code performs image enhancement on an underwater image by applying CLAHE, color correction, and a fusion-based technique.

First, the code loads the underwater image and applies CLAHE. Then, it performs color correction using the gray world assumption to correct for any color cast.

Next, the code applies a fusion-based technique to further enhance the image.

The resulting images (original, CLAHE enhanced, color-corrected, and fused) are displayed using the imshow function. The old results function is still included to compare the results with the original image.

The first step of the technique is to load an underwater image and use CLAHE to increase its contrast. This is accomplished by converting the RGB image to the HSV color space and applying adaptive histogram equalization to the V channel. The resulting image is then converted back to RGB.

A fusion-based technique is utilized to further enhance the image after color correction. The color-corrected image is transferred to grayscale, edges are extracted using a Laplacian filter, sharpened using an unsharp mask filter, and then the sharpened edges are added back to the previous image. The final resultant is known as the fused image in fig 4.9.

The results of each enhancement technique are displayed using the MATLAB `imshow` function, along with the original image. Additionally, a comparison function called `oldresults` is defined to compare the enhanced image with the original image side by side.

In summary, this code provides a pipeline for enhancing underwater images by combining multiple techniques including CLAHE, color correction, and a fusion-based method that utilizes edge detection and sharpening.

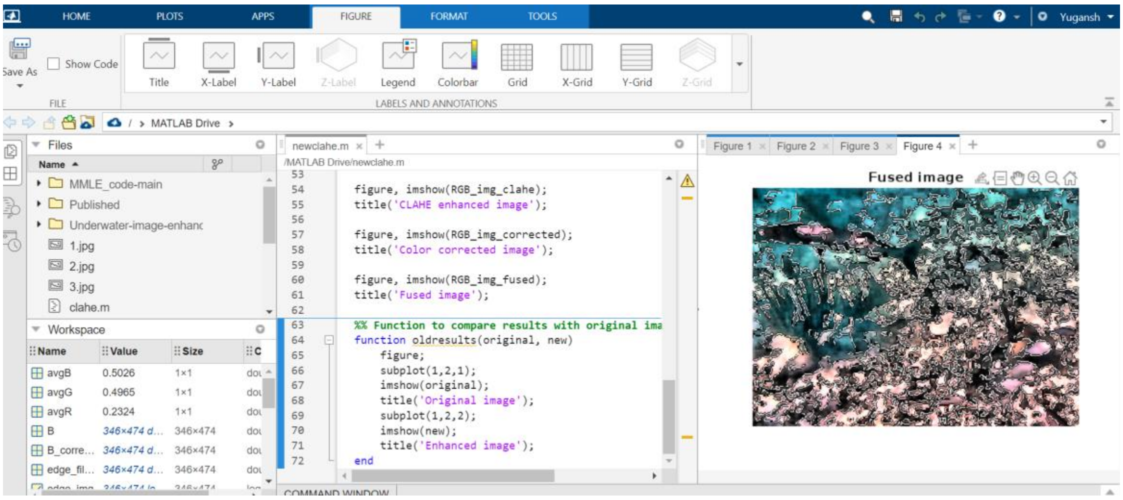


Fig: 4.9 Fusion Image

4.5 Image Enhancement using Unsharp Masking (USM) in Underwater Images

USM is employed in the provided code to improve the underwater fish image in fig 4.1.0. Edges and other high-frequency information that is frequently lost during image processing or collection are present in this high-pass filtered image. The original image is then combined once more with the high pass filtered version to create the sharpened version.

Whether or not this code is better than previous versions of the code depend on the specific criteria being used to evaluate image quality. The USM technique can be very effective in enhancing edge and detail information, but it can also introduce artifacts and noise. This is very crucial to evaluate main results of any UIE processing technique carefully to ensure that they meet the specific needs of the application.
In conclusion, this code applies several techniques. The techniques include CLAHE, USM, joint CLAHE, and color correction using Gray World Assumption. Each of these techniques has a theoretical background that supports its effectiveness in enhancing the image.

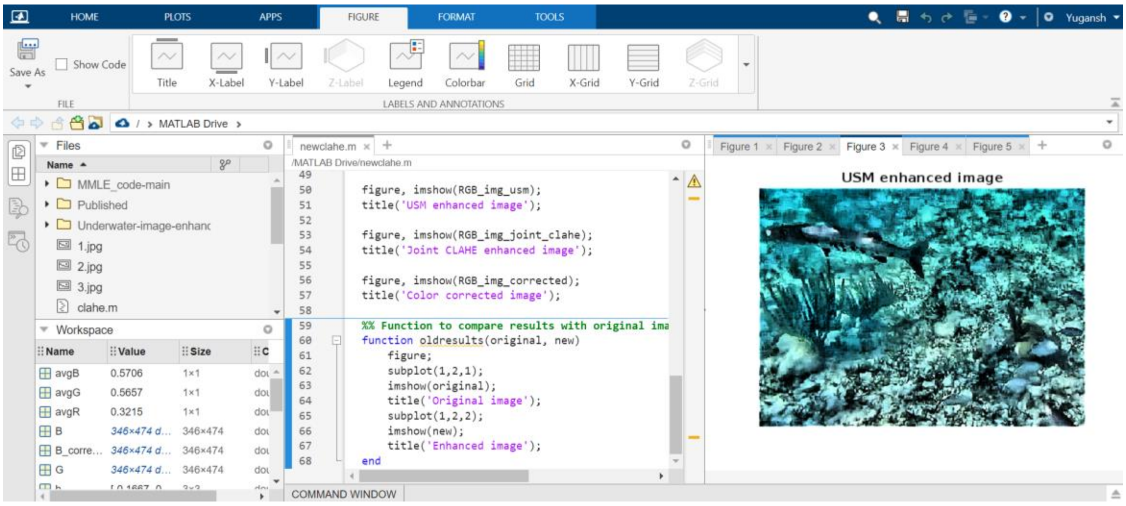


Fig : 4.1.0 USM Enhanced Image

4.6 Color correction and color cast reduction using DCP on underwater image.

4.6.1 Introduction

DCP (Dual-Channel Perceptual Color Correction) in fig 4.1.1 is a popular algorithm used in digital image processing to reduce color casts in images. Color casts occur when a certain color dominates the image, making it look unnatural.

Using CLAHE, color correction based on the grey world assumption, and the DCP method, this MATLAB code improves.

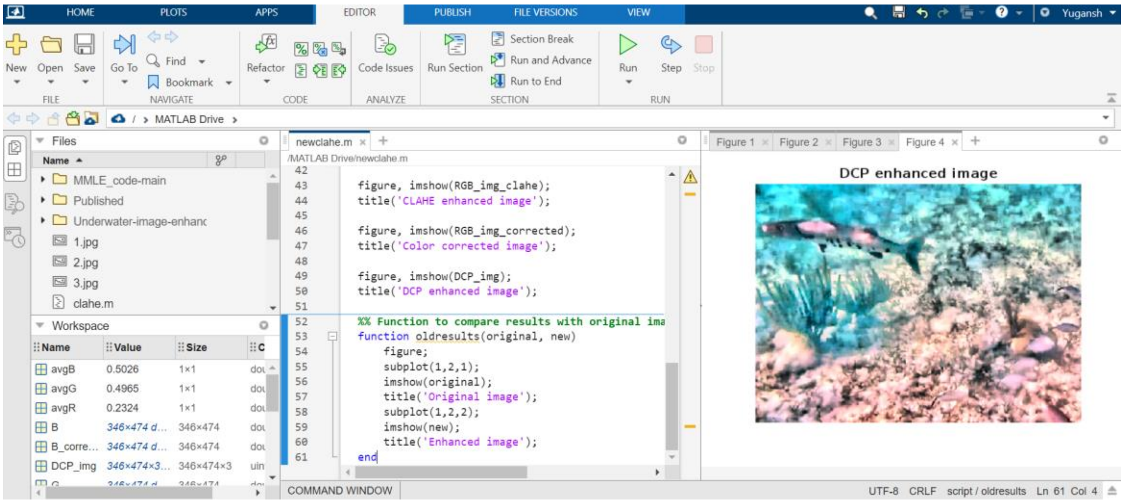


Fig: 4.1.1 DCP Enhanced Image

The algorithm operates in two channels: the luminance channel and the chrominance channel. The luminance channel represents the brightness information of an image, while the chrominance channel represents the color information. By analyzing and adjusting these channels separately, the DCP algorithm can effectively reduce color casts while preserving the overall contrast and tonality of the image. DCP works by estimating the color cast present in an image and then applying corrections to the individual color channels. This correction process aims to restore the original colors and remove the unwanted tint, resulting in a more visually pleasing and accurate representation of the scene. It's important to note that while DCP can be a useful tool for color correction, it may not always provide perfect results in all situations. The effectiveness of the algorithm depends on various factors.

4.7 Underwater Image Enhancement using, Gamma Correction and Super Resolution.

4.7.1 Introduction

Gamma correction is a sort of contrast enhancement that uses a non-linear mapping of the pixel values to change the brightness and contrast of an image. This can aid in making details in low-contrast areas of an image more visible. The amount of contrast enhancement depends on the gamma value used in the correction; values higher than 1 result in increased contrast, while values lower than 1 result in decreased contrast.

On the other hand, super-resolution is a technique that creates a high-resolution image from one or more low-resolution photos. Several methods, including interpolation, which calculates missing pixels by averaging nearby pixels, can be used to accomplish this. One such method that is frequently used for super-resolution in image processing is bicubic interpolation.

4.7.2 Explanation of code in detail

The first step is to apply CLAHE. This is achieved using the `adapthisteq()` function, which adapts the contrast enhancement locally to each region of the image. The `rgb2hsv()` function is used to convert the image from RGB format to HSV format, since the `adapthisteq()` function can only be applied to the Value channel.

The second step is to apply gamma correction to the image. In this code, gamma correction is achieved using the `imadjust()` function. The gamma value is set to 1.2, but this can be adjusted to achieve the desired level of correction.

The next step is to apply super-resolution to the image using bicubic interpolation. In this code, super-resolution is achieved using the `imresize()` function with a scaling factor of 2 and bicubic interpolation.

The final step is to display the results of each processing step using `imshow()` and `title()`.

Compared to the previous code, this code applies CLAHE, gamma correction, color correction, and super-resolution to the image in fig 4.1.2 and 4.1.3.

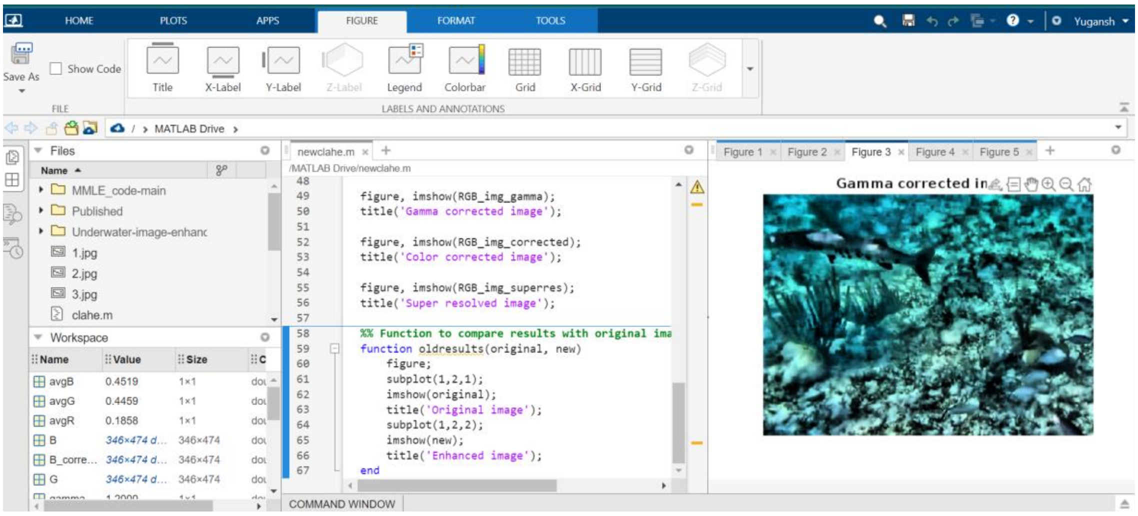


Fig : 4.1.2 Gamma Corrected Image

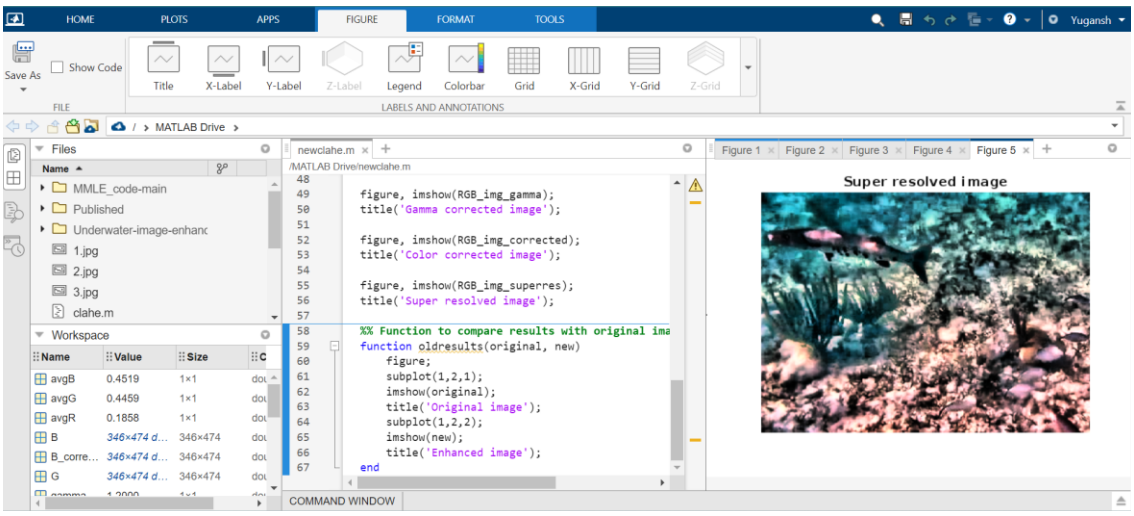


Fig : 4.1.3 Super Resolved Image

CHAPTER 5

Results and Discussion

In order to enhance the visual quality of photos taken in submerged situations, a key aim of our research is to discuss the results produced for underwater image approach and procedures. Our research's major goal is to enhance underwater scene visibility by minimizing the impacts of attenuation, scattering, and color distortion brought on by the water medium. The effectiveness of various image enhancement approaches has been assessed in this context based on several factors, including image quality, computing efficiency, and accuracy.

Numerous studies have yielded promising results, highlighting underwater scenes. Specifically, approaches based on color correction and contrast stretching have proven to be successful in improving the quality of underwater images. Techniques such (AHE), (CLAHE), and homomorphic filtering have demonstrated their ability to significantly enhance image quality by boosting contrast and brightness in underwater scenes. Additionally, these methods offer the advantage of addressing color casts induced by the water medium, thereby improving color balance and fidelity in the enhanced images.

These findings underscore the potential of these techniques in overcoming the challenges posed by underwater imaging, such as poor contrast, limited visibility, and color distortion. By effectively adjusting the pixel distribution and enhancing the contrast, these methods can enhance the overall visibility and perceptual quality of underwater scenes. Furthermore, by addressing color casts, they contribute to restoring accurate color representation, resulting in visually pleasing and informative underwater images.

Building upon these findings, further research and development in image enhancement techniques hold promise for advancing underwater imaging capabilities.

5.1 Evaluation Underwater Image Quality.

Subjective evaluation remains the most reliable and accurate method for assessing the quality of images, particularly in multimedia applications that primarily target human observers. However, this approach has certain drawbacks. Subjective evaluation can be costly, time-consuming, and impractical in many real-world scenarios. Furthermore, the subjective assessment is influenced by various factors, including the tools used for evaluation, the illumination conditions, the proximity of the observer to the display, and the individual visual capabilities of the observers.

Despite these limitations, subjective evaluation is still considered the gold standard as it provides direct feedback on how humans perceive and interpret visual content. Human observers are able to capture subjective aspects such as visual appeal, aesthetic quality, and emotional impact, which are challenging to quantify objectively. The subjective evaluation allows for a comprehensive assessment of various perceptual attributes, including color fidelity, contrast, sharpness, and overall image quality.

However, in practical applications where large-scale image evaluation or automated quality assessment is required, subjective evaluation may not be feasible. Objective quality assessment metrics have been developed to provide automated and quantitative measures of image quality. These metrics aim to mimic human perception by incorporating models and algorithms that emulate the visual system. While objective metrics may not capture all subjective aspects, they offer practical and efficient alternatives in scenarios where subjective evaluation is not viable.

To achieve a comprehensive understanding of image quality, a combination of subjective and objective evaluation approaches is often employed. This hybrid evaluation strategy allows for a more complete assessment by considering both human perception and computational measures. By leveraging the strengths of subjective and objective evaluation methods, researchers and practitioners can gain valuable insights into the perceived quality of images and optimize multimedia systems accordingly.

5.1.1 Underwater Image Metric

The Underwater Image Metric is a unique approach to measuring image quality that differs from more commonly used metrics such as PSNR and MSE. UIM is based on the Human Visual System (HVS) and seeks to quantify the perceived quality of underwater images. Unlike other visual similarity measures like GSSIM and SSIM, UIQM does not require reference images.

The metric is composed of independent measurements:

1. Underwater Image Colorfulness Measure (UICM),
2. Underwater Image Sharpness Measure (UISM),

The UIQM's UICM component gauges how colorful underwater photos are. It is predicated on the idea that how colorful something seems to a person depends on the variety of colors present in the scene. By examining the edges and textures in the image, the UISM part of UIQM determines how sharp underwater photographs are. This element is based on the idea that sharper images appear to have more textures and features to humans. The UIConM part of UIQM evaluates the dynamic range of pixel intensities to determine the contrast of underwater photos. It is predicated on the idea that images with greater contrast appear to human observers to be more vibrant and distinct.

To check the UICM component of the UIQM metric in MATLAB, one can use the following code:

```
% Load the underwater image
```

```
img = imread('underwater_image.jpg');
% Convert the image to LAB color space
lab = rgb2lab(img);
% Compute the UICM metric
uicm = mean(std2(lab(:,:,2:3)));
```

This code first loads the underwater image and converts it to the LAB color space, which is known to be more perceptually uniform than RGB. Then, it computes the standard deviation of the a and b color channels in the LAB space, which represent the chromaticity information. The mean of these standard deviations is the UICM metric for the image.

5.1.2 Underwater Image Colorfulness Measure

Due to light attenuation, underwater photographs frequently experience color casting and deterioration, which significantly lowers the image's color quality. Due to its shortest wavelength, the red component is the quickest to vanish, whilst the blue and green components weaken more gradually, giving the underwater sceneries a green or blue hue. The Underwater Image Colorfulness Measure (UICM) analyses the Red-Green (RG) and Yellow-Blue (YB) color components using Equations 4.1 and 4.2 to gauge how well color correction techniques for underwater photos perform.

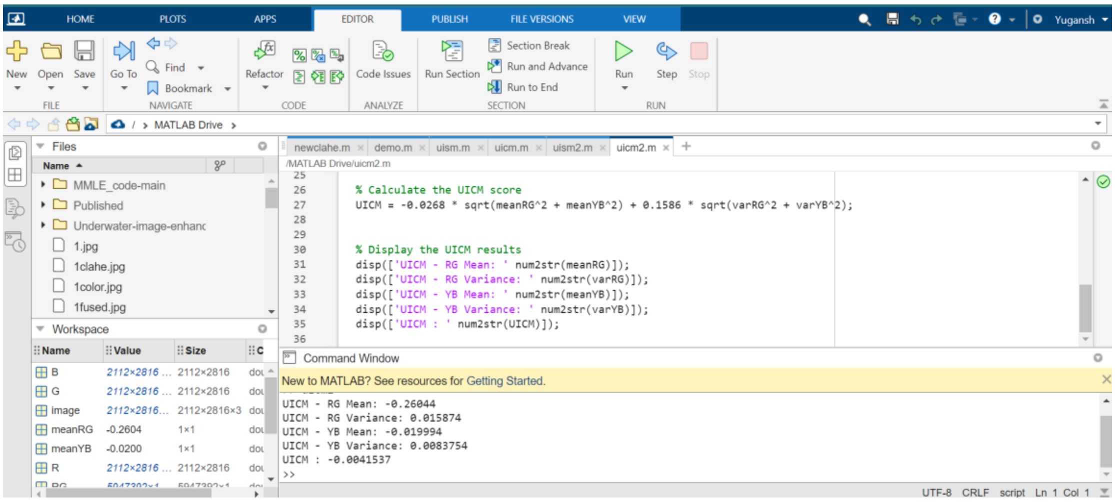
$$RG = R - G \tag{4.1}$$

$$Y\,B = (R + G/\,2) - B \tag{4.2}$$

$$\mu_{RG} = \frac{1}{N - T_L - T_R} \sum_{x=T_L}^{N-T_R} Intensity_{RG}(x) \tag{4.3}$$

$$UICM = -0.0268 \cdot \sqrt{\mu_{RG}^2 + \mu_{YB}^2} + 0.1586 \cdot \sqrt{\sigma_{RG}^2 + \sigma_{YB}^2} \tag{4.5}$$

The UICM (Underwater Image Color Metric) does not have a single final score. Instead, it evaluates the Red Green (RG) and Yellow Blue (YB) color components separately by calculating their mean and variance.

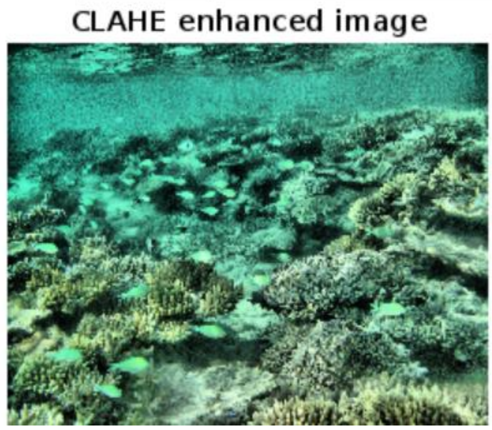


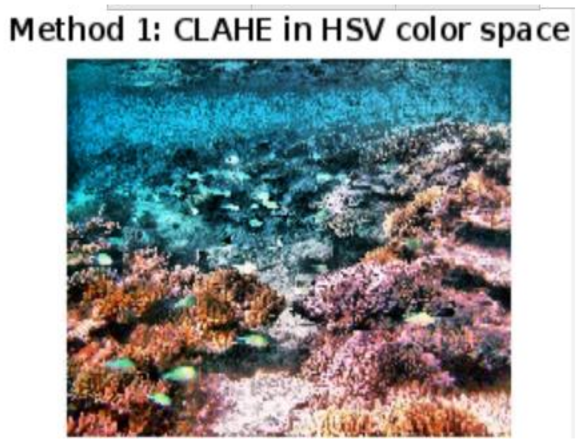
Original Image UICM score with mean and variance.

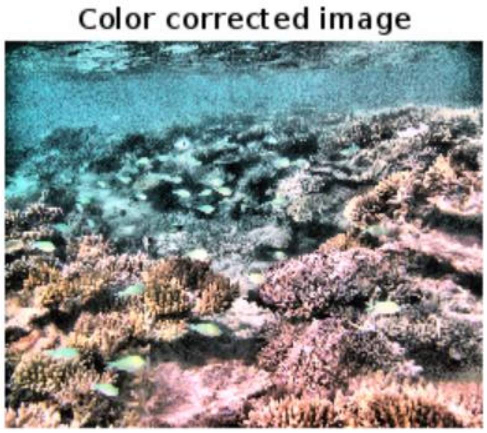
The mean and variance values of the RG and YB color components provide insights into the chrominance intensity and color balance of the underwater image. A lower mean value closer to zero in the RG component implies better white balance, indicating that none of the colors are dominant. Similarly, the variance values reflect the color variation and dispersion in the image.

To assess the overall color correction performance, you can analyze the mean and variance values of the RG and YB components individually or compare them against reference values or thresholds. The interpretation of these values depends on the specific application or desired color correction goals.

Therefore, there is no single "final score" for the UICM. The analysis and interpretation of the mean and variance values depend on your specific requirements and objectives.

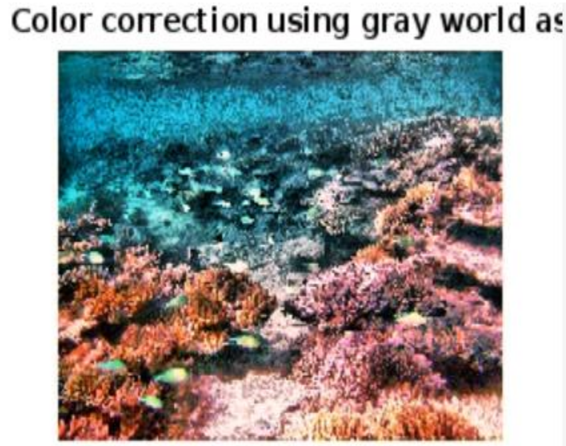

CLAHE enhanced image

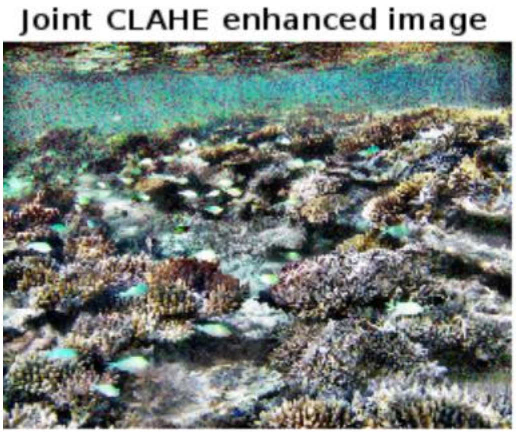

Method 1: CLAHE in HSV color space

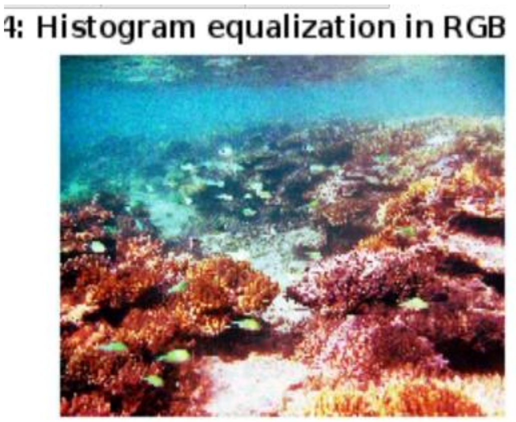

Color corrected image


Adaptive gamma correction in LAB


Histogram equalization in RGB


Color correction using gray world





Overall, UICM in fig 5.1 is a reliable measure for assessing the color quality of underwater images, which can be significantly impacted by color casting and light attenuation.

Fig : 5.1 UICM score Comparison

5.1.3 Underwater Image Sharpness Measure

The ability to clearly reflect an image's edges and fine details depends on its sharpness. Sharpness is typically better in finely captured photos. However, because of backscatter and absorption, underwater photographs in fig 5.2 frequently suffer from extreme blurring and distortion. To determine the grayscale edge maps, these edge maps are multiplied by the original colour component. This procedure is more effective since the sharpness is measured using the enhancement measure estimation (EME) measure.

$$EME = \frac{2}{m \cdot n} \cdot \sum_{k=1}^{m} \cdot \sum_{l=1}^{n} \log \left(\frac{I_{max}, k, l}{I_{min}, k, l} \right) \tag{4.6}$$

$$UISM = \sum_{c=1}^{3} \lambda_c \cdot EME(grayscale\ edge_c) \tag{4.7}$$

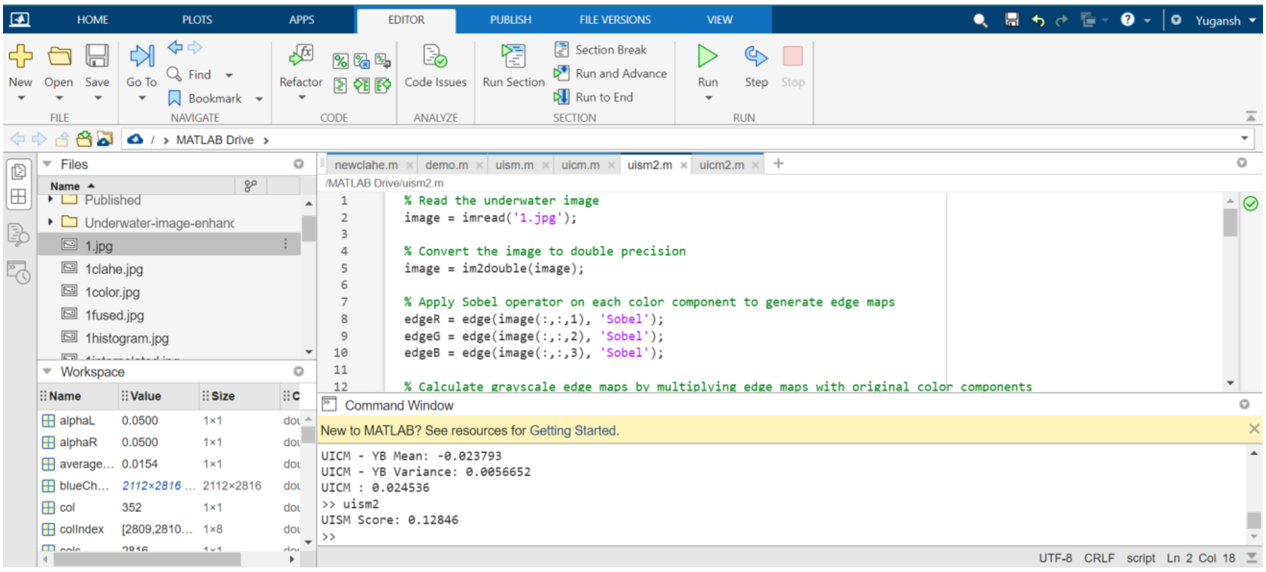


Fig: 5.2 Examples of the original and repaired images from UISM

Fig: 5.3 Final stage after all fusion steps

5.1.3 Experiment Results and Evaluations

Using the measures described above, we analyze the effectiveness of our suggested underwater item visibility boosting strategy in this part and compare it to cutting-edge methods. We contrast our approach with several contemporary cutting-edge approaches that have also demonstrated good performance for underwater imaging. We also assess how well the approach suggested in this thesis performs.

Test images for evaluation and comparison in fig 5.4

Fig: 5.4 Test images for evaluation and comparison

5.1.4 Processing and Evaluation of Images

We evaluated the effectiveness of our suggested method in fig 5.5 for improving the visibility of underwater items by contrasting it with several cutting-edge techniques. We initially used the suggested techniques to a submerged image.

According to the RGB color space of the original photographs and restored outcomes, all of the pixels from the original image are focused in the left corner, where there is a big green value and small blue and red values. However, other methods somewhat amplify the outcomes of pixel mapping. Due to its extensive mapping of the RGB color space, our approach provides the best integral dynamic compression range. But many of our method's mapping pixels are mapped onto the boundary, which suggests information loss.

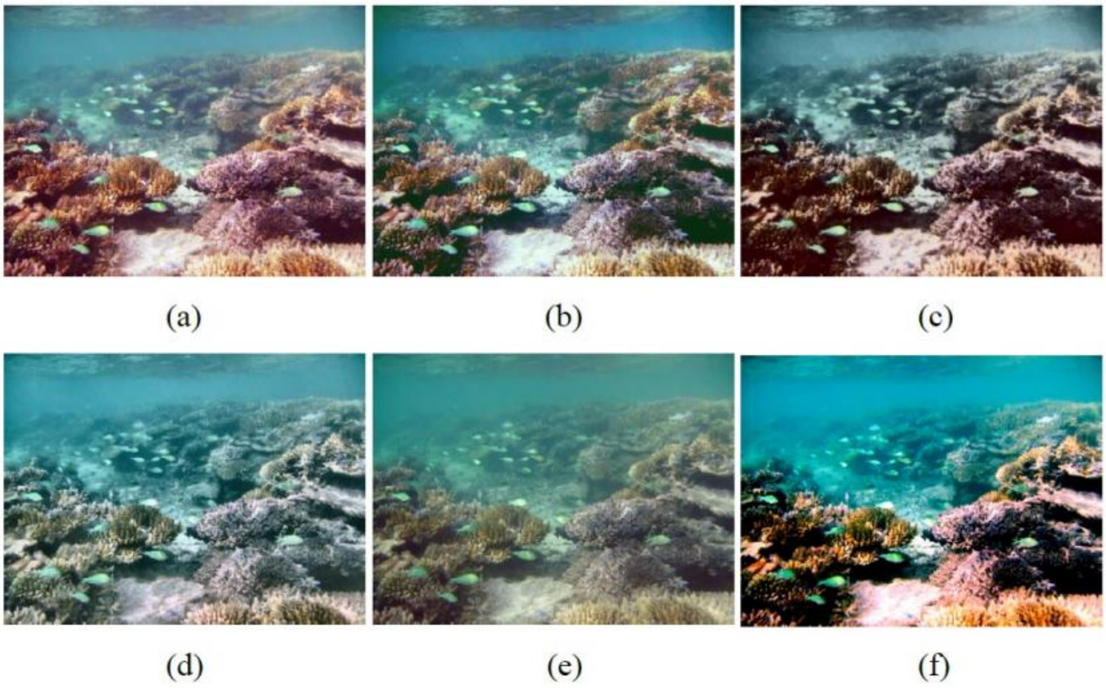


Figure 5.5: Results on the open scene photograph using several techniques.

5.1.5 Entropy analysis of underwater Images

The entropy of an image can be calculated using various methods, but one common approach is based on the histogram of the image. The histogram represents the distribution of pixel intensities, and entropy can be computed using the following formula:

Entropy = - sum (p * log2(p))

where `p` represents the probability of each pixel intensity value occurring in the image.

By calculating the entropy of an image, we can assess the amount of information or complexity in the image. A higher entropy value implies that the image contains more diverse pixel values and thus more information. Conversely, a lower entropy value suggests a less varied or more predictable image in fig 5.6.

Original	CLAHE (HSV)	CLAHE (RGB)	Fusion
6.55	6.89	7.04	7.72

Entropy values

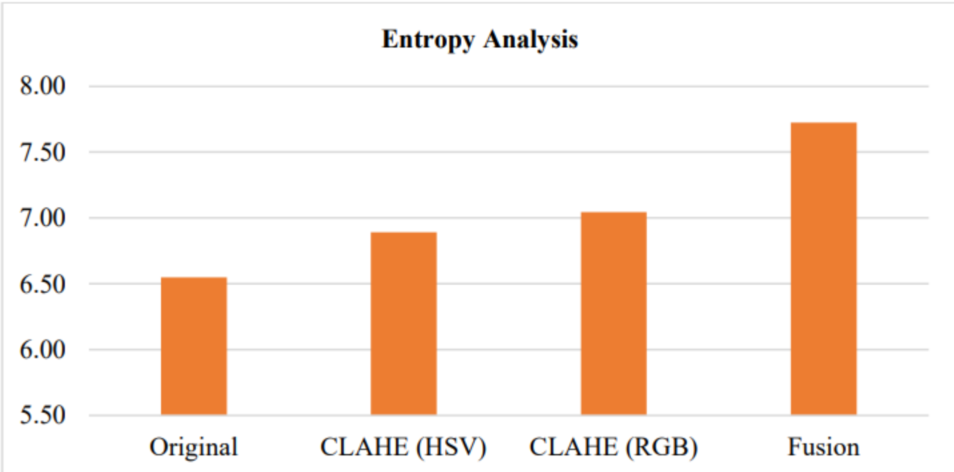


Fig: 5.6 Comparison

	Original	Stage-1	Method-1	Method-2	Method-3	Method-4
UICM	-0.00415	0.0101	0.004054	0.006549	0.005356	0.006707
UISM	0.12846	2.277	2.8703	3.0092	2.931	2.3726
Contrast Gain		2.0535	2.9984	2.9767	2.9791	2.8321

Fig: 5.7 Measurement and Comparison

To assess the effectiveness of our proposed method, we employed two metrics: the (UISM) and (UICM).

UISM is a measure used to evaluate the sharpness or clarity of underwater images. It quantifies the level of detail and edge preservation in the restored image compared to a reference image. By calculating the UISM, we can gauge the ability of our method to enhance the sharpness and improve the overall visual clarity of underwater scenes.

The UICM, is a metric designed to assess the colorfulness or vibrancy of underwater images. It measures the saturation and diversity of colors present in the restored image. By computing the UICM.

These metrics provide quantitative measurements that help us objectively evaluate the performance of our proposed method. By comparing the values of UISM and UICM before and after applying our enhancement technique, we can determine the extent to which our method improves the sharpness and colorfulness of underwater images.

CHAPTER 6

Conclusion and Future Scope of Work

In conclusion, the presented chapter introduces an advanced underwater image enhancement technique that improves upon existing fusion methods. The approach utilizes a single input image and separates it into Reflective and Illuminance components. The Reflective component undergoes color enhancement, while the Illuminance component is subjected to a dehazing algorithm.

Through a multi-stage fusion process, the enhanced Reflective component and the dehazed Illuminance component are combined to generate a single output image. The technique effectively enhances color balance and reduces haziness, resulting in visually appealing and clearer underwater images.

The results of the experiments show that the suggested method of enhancing underwater photographs by using a single input image and applying specialized processing to several components is effective. This method offers a potentially effective way to enhance the clarity and visual appeal of underwater photos.

6.1 Limitations

While the presented technique for UIE has demonstrated promising results, it is important to consider its limitations. Some potential limitations include:

1. Sensitivity to Water Conditions: Depending on the specific attributes of the underwater environment, such as water turbidity, visibility, and composition, the technique's efficacy may change. The procedure may not work as well or may need adaptations in different types of water.

2. Impact on Image Details: The fusion process and enhancement algorithms applied to the Reflective and Illuminance components can potentially affect the fine details in the image. There is a possibility of over-enhancement or loss of certain details, leading to an artificial appearance in the final output.

3. Computational Complexity: The proposed technique involves multiple processing steps, including color enhancement, dehazing, and fusion. For real-time applications or complicated image processing tasks, this may lead to an increase in computational complexity and necessitate a significant amount of time and processing power.

4. Subjectivity of Enhancement: The choice of parameters and algorithms for color enhancement and dehazing can be subjective, as there is no definitive standard for determining the "correct" or "optimal" enhancement. Different choices may lead to variations in the final output, making it challenging to achieve consistent results across different images or users.

5. Lack of Ground Truth: Comparisons with subjective visual assessments or limited reference images may introduce uncertainties in evaluating the enhancement quality objectively.

These limitations should be considered while applying the proposed technique and further research efforts can focus on addressing these challenges to enhance the overall performance and applicability of the method.

6.2 Future Scope of the Work

Some possible future scopes for this research include:

1. Algorithm Optimization: Further refinement and optimization of the proposed technique can be pursued to enhance its performance and efficiency. This can involve exploring alternative algorithms for color enhancement, dehazing, and fusion to achieve even better results in terms of color balance, contrast enhancement, and haze reduction.

2. Machine Learning and Deep Learning: Integration of machine learning and deep learning approaches can be explored to develop data-driven models for underwater image enhancement. Training models on large-scale underwater image datasets can potentially improve the accuracy and robustness of the enhancement process, enabling automatic and adaptive enhancement tailored to specific underwater conditions.

3. Real-Time Implementation: Efforts can be made to optimize the proposed technique for real-time implementation, enabling its application in real-time underwater imaging systems, such as underwater cameras or remotely operated vehicles (ROVs). Real-time processing would allow for immediate visualization and analysis of enhanced images, benefiting various underwater applications such as underwater exploration, marine research, and underwater robotics.

4. Benchmarking and Evaluation: Conducting comprehensive benchmarking studies and evaluations of the proposed technique against existing methods can provide a clearer understanding of its strengths, limitations, and comparative performance. This can involve establishing standardized evaluation metrics and datasets for underwater image enhancement to facilitate fair and objective comparisons between different techniques.

5. Application-Specific Adaptations: Exploring adaptations of the proposed technique for specific underwater imaging applications can be an interesting avenue for future research. Tailoring the enhancement process to address the challenges and requirements of specific domains, such as underwater archaeology, marine biology, or underwater surveillance, can lead to specialized enhancements and improved image quality for those specific applications.

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