A

Project Report

On

Under Water Image Enhancement Based on Adaptive Color Correction and Improved Retinex Algorithm

Submitted to

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR, ANANTHAPURAMU

In partial fulfillment of the requirement for the award of the degree of

BACHELOR OF TECHNOLOGY

In

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

SRI VENKATESWARA COLLEGE OF ENGINEERING

(Approved by AICTE, New Delhi & Affiliated to JNTUA, Ananthapuramu)

Balaji Nagar, KADAPA– 516003

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CERTIFICATE

This is to certify that the project report entitled **"Under Water Image Enhancement Based on Adaptive Color Correction and Improved Retinex Algorithm"** *bonafide record of the project work done and submitted by*

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External Viva-Voce Exam Held On________________________________

INTERNAL EXAMINER **EXTERNAL EXAMINE**

DECLARATION

We here by declare that the project report entitled "**Underwater Image Enhancement Based on Adaptive Color Correction and Improved Retinex Algorithm"** submitted to the department of requirement for the award of the degree of **BACHELOR OF TECHNOLOGY.** This project is the result of our own effort and that it has not been submitted to any other university or institution for the award of any degree or diploma other than specified above.

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LIST OF CONTENTS

ABSTRACT

In order to solve the problems about color distortion and low contrast of underwater images, we propose an underwater image enhancement algorithm that combines adaptive color correction with improved Retinex algorithm. Our algorithm is a single-image enhancement method that does not require specialized hardware and underwater scenes prior. Firstly, the adaptive color correction is carried out on the underwater distorted images to solve the color cast problem effectively. Then, on the one hand, we use the image decomposition to strengthen the detail part and obtain a detail enhanced image. On the other hand, we use the improved Retinex algorithm to strengthen the edge part and obtain an edge enhanced image. Finally, the detail enhanced image and the edge enhanced image are fused based on the non-subsampled shearlet transform (NSST) to obtain the final enhanced underwater image. The results show that our method outperforms several state-of-the-art methods about underwater image enhancement in terms of PCQI, UCIQE, UIQM and IE. By scale invariant feature transform (SIFT) algorithm, we calculate the number of feature matching points of the input image and the enhanced image, and our proposed method achieves the best experimental results. The source code of our proposed algorithm is available at: https://github.com/lin9393/ underwater-image-enhance.

INDEX TERMS: *Underwater image enhancement, adaptive color correction, improved Retinex algorithm, non-subsampled shearlet transform.*

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

DCP	Dark Channel Prior
NSST	Non-Subsampled Shearlet Transform
PCQI	Perceptual Color Image Quality
UCIQE	Underwater Color Image Quality Evaluation
UIQM	Underwater Image Quality Measure
IE	Image Entropy
SIFT	Scale Invariant Feature Transform
DIP	Digital Image Processing
MRI	Magnetic Resonance Imaging
CT	Computed Tomography
JPEG	Joint Photographic Experts Group
PNG	Portable Network Graphics
RGB	Red Green Blue
HSV	Hue, Saturation, Value
CMYK	Cyan Magenta Yellow Key
AI	Artificial Intelligence
OCR	Optical Character Recognition
AR	Augmented Reality

CHAPTER 1

INTRODUCTION

With the increasing shortage of resources on land, the ocean, which is rich in oil and mineral resources, has been eagerly explored. Obtaining high-quality and clear underwater images is an important guarantee for the development of underwater vehicle control, underwater infrastructure inspection, and marine biological research. Therefore, enhancing the visual effects of underwater images is an important part of ocean exploration.

However, due to the attenuation and scattering of light in water, problems such as color cast, image blurring, and low contrast appear in underwater images. With the increased human utilization of the ocean, underwater robot technology has developed significantly, allowing for artificial underwater operations to be replaced under complicated working conditions. The primary environmental perception method of underwater robots is obtaining image information through an underwater vision system. However, due to the scattering and absorption effects of the water, the image enhancement captured by the system is not ideal.

In the traditional DCP algorithm applied to underwater image enhancement, there is an issue where the depth-of-field effect of the dark channel image is not obvious, and the environmental color of the water cannot be accurately estimated. Additionally, applying the DCP algorithm often causes excessive enhancement in waters with high illumination. The Retinex algorithm, used for underwater image enhancement, is not ideal for processing noisy images, making the algorithm less robust.

Tang Zhongqiang et al. used the difference between the bright and dark channels to obtain a depth map, then used the depth map to estimate the background color of the water to effectively acquire depth information and improve the original dark channel algorithm. Li Shelei et al. used the dark primary colors prior algorithm to deblur underwater color images and improved the estimation method of the background light intensity a value for the uneven brightness of the water caused by artificial lighting. Finally, a statistical method was used to determine the three color channels R, G, and B, which were then color-corrected to realize the overall correction of underwater image color.

Huo Guangyao et al. used the dark channel principle to defog underwater images, introduced adaptive red channel compensation parameters to improve the phenomenon of red light loss, and combined it with the vignetting model to correct the brightness channel of the underwater image, reducing the impact of light intensity on image quality. He Xiao et al. performed gamma correction on the image by selecting gamma parameters, then used single-scale Retinex for enhancement to correct underwater image color distortion. Yang Fuhao et al. used the inconsistency in the attenuation of light of different wavelengths by water to adaptively compensate the R, G, and B channels, then applied Retinex based on multi-scale guided filtering to remove foggy blur and enhance contrast. Finally, according to the histogram distribution characteristics of underwater images and natural images, normalization was performed to optimize the visual perception effect.

Through the analysis of the above research, it can be seen that a single enhancement algorithm performs well in a specific illumination range, but there are limitations to using a single enhancement algorithm across the full illumination range. For this reason, this paper proposes an improved DCP and Retinex algorithm for underwater image enhancement, utilizing corresponding algorithms to enhance different illumination domains.

1.1 Introduction to Digital Image Processing

Digital Image Processing means processing digital image by means of a digital computer. We can also say that it is a use of computer algorithms, in order to get enhanced image either to extract some useful information.

Digital image processing is the use of algorithms and mathematical models to process and analyze digital images. The goal of digital image processing is to enhance the quality of images, extract meaningful information from images, and automate image-based tasks.

1.1.1 Definition of Digital Image Processing

Digital Image Processing refers to the use of computer algorithms to perform operations on digital images to enhance their quality, extract useful information, or prepare them for further analysis. It involves techniques such as filtering, noise reduction, image enhancement, segmentation, compression, and object recognition.

Key Aspects of Digital Image Processing:

Image Acquisition: Capturing images using devices like cameras or scanners.

Preprocessing: Removing noise, correcting distortions, and enhancing image quality.

Segmentation: Dividing an image into meaningful regions for analysis.

Feature Extraction: Identifying important features such as edges, shapes, and textures.

Image Compression: Reducing the file size for efficient storage and transmission.

Pattern Recognition: Detecting objects, patterns, or anomalies in images.

Restoration and Enhancement: Improving image clarity and restoring damaged images.

Digital image processing is widely used in areas like medical imaging, remote sensing, computer vision, robotics, and more

1.1.2 Features of Digital Image Processing

Digital Image Processing has several key features that make it a powerful tool for analysing and enhancing images.

Image Enhancement improves visual quality by adjusting brightness, contrast, and sharpness.

Image Restoration corrects defects caused by noise, motion blur, or sensor limitations.

Image Compression reduces file size for efficient storage and transmission using lossy (JPEG) or lossless (PNG) methods.

Image Segmentation divides an image into meaningful regions to detect objects or patterns.

Edge Detection and Feature Extraction identify boundaries and key features for object recognition and classification.

Color Image Processing handles different color spaces like RGB, HSV, and CMYK for better analysis.

Morphological Processing analyzes the shape and structure of objects in an image, commonly used in object recognition.

Pattern Recognition helps in identifying and classifying objects, faces, or patterns, often used in AI and biometric systems.

Image Filtering applies techniques like Gaussian and Median filters to smooth, sharpen, or enhance images.

3D Image Processing works with three-dimensional images, widely used in medical imaging and computer vision.

Real-Time Image Processing enables instant image analysis for applications like facial recognition, robotics, and video surveillance.

Object Detection and Tracking identifies and follows objects in images or videos, playing a crucial role in autonomous vehicles and security systems.

These features make Digital Image Processing essential in various fields, including healthcare, artificial intelligence, and remote sensing.

1.1.3 Fundamentals of an Image & Digital Image Processing

What is an image?

An image is defined as a two-dimensional function, **F(x, y)**, where x and y are spatial coordinates, and the amplitude of **F** at any pair of coordinates (x, y) is called the **intensity** of that image at that point. When x,y, and amplitude values of **F** are finite, we call it a **digital image**. In other words, an image can be defined by a two-dimensional array specifically arranged in rows and columns. Digital Image is composed of a finite number of elements, each of which elements have a particular value at a particular location. These elements are referred to as *picture elements, image elements, and pixels*. A *Pixel* is most widely used to denote the elements of a Digital Image.

Image as a Matrix

As we know, images are represented in rows and columns we have the following syntax in which images are represented:

$$
f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & f(0,2) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & f(1,2) & \cdots & f(1,N-1) \\ \vdots & \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & f(M-1,2) & \cdots & f(M-1,N-1) \end{bmatrix}
$$

Fig 1.1: Image as a Matrix

The right side of this equation is digital image by definition. Every element of this matrix is called image element, picture element, or pixel.

An image is a rectangular grid of pixels. It has a definite height and a definite width counted in pixels. Each pixel is square and has a fixed size on a given display. However different computer monitors may use different sized pixels. The pixels that constitute an image are ordered as a grid (columns and rows); each pixel consists of numbers representing magnitudes of brightness and color.

Each pixel has a color. The color is a 32-bit integer. The first eight bits determine the redness of the pixel, the next eight bits the greenness, the next eight bits the blueness, and the remaining eight bits the transparency of the pixel.

1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1
Transparency	Red	Green	Blue

Fig 1.2: Transparency image

Gray scale image:

A grayscale image is a function I (xylem) of the two spatial coordinates of the image plane.

I(x, y) is the intensity of the image at the point (x, y) on the image plane.

I (xylem) takes non-negative values assume the image is bounded by a rectangle [0, a] ×[0, b] I: [0, a] × [0, b] → [0, info]

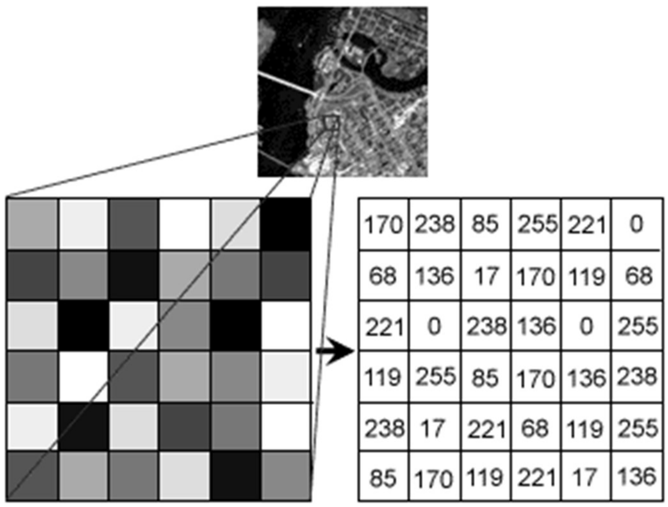


Fig 1.3: Gray Scale Image Pixel

Color Image Processing

Color image processing is motivated by the fact that using color it is easier to classify and the human eye can easily see thousands of colors than shades of black and white. Color image processing is divided into types - pseudo color or reduced color processing and full color processing. In pseudo color processing, the grey scale is applied to one color. It was used earlier. Now-a-days, full color processing is used for full color sensors such as digital cameras or color scanners as the price of full color sensor hardware is reduced significantly.

There are various color models like RGB (Red Green Blue), CMY (Cyan Magenta Yellow), HSI (Hue Saturation Intensity). Different color models are used for different purposes. RGB is understandable for computer monitors. Whereas CMY is understandable for a computer printer. So there is an internal hardware which converts RGB to CMY and vice versa. But humans cannot understand RGB or CMY, they understand HSI.

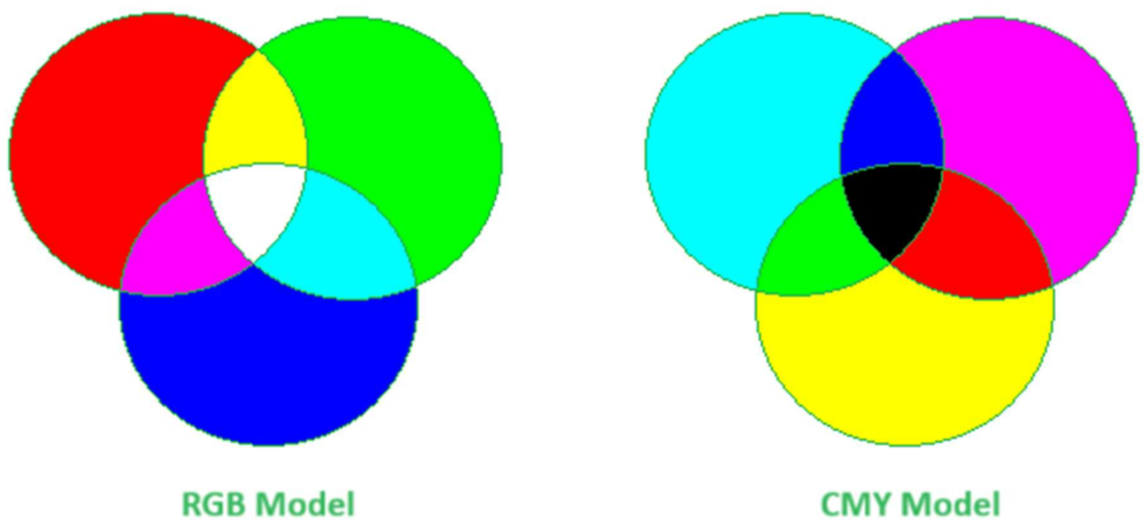


Fig 1.4: RGB and CMY model

1.1.4 Overview of a Digital Image processing.

Digital Image Processing (DIP) is a field of computer science that involves the manipulation and analysis of digital images using computational techniques. Unlike traditional analog image processing, DIP converts images into numerical data, enabling various operations such as enhancement, restoration, segmentation, and recognition. A digital image is represented as a two-dimensional function, where and are spatial coordinates, and denotes the intensity or color at that point. When these values are finite and discrete, the image is classified as a digital image.

Digital image processing has a wide range of applications across various industries. In medical imaging, techniques such as MRI, CT scans, and X-ray analysis help in diagnosis and treatment. Remote sensing utilizes satellite images for environmental monitoring and urban planning. Object tracking is extensively used in surveillance systems to detect and track motion. In industrial automation, DIP is employed for defect detection and quality control in manufacturing. Forensics and security applications include facial recognition, fingerprint analysis, and biometric authentication.

In conclusion, digital image processing is a crucial technology that plays a fundamental role in modern computer vision, artificial intelligence, and scientific research. By utilizing advanced computational techniques, DIP enables the extraction of valuable information from images, leading to innovations in healthcare, security, automation, and beyond

1.1.5 Applications of Digital Image Processing

Digital image processing has a wide range of applications across various fields. These applications leverage the ability to manipulate, analyze, and enhance images for specific purposes. Here are some key areas where digital image processing is widely applied:

1. Medical Imaging

Diagnosis and Treatment: Image processing techniques are widely used in analyzing medical images like X-rays, CT scans, MRIs, and ultrasound images to detect and diagnose conditions such as tumors, fractures, or abnormal growths.

Image Enhancement: Enhancing images to highlight certain features, such as blood vessels or tumors, which might otherwise be hard to detect.

3D Imaging: Creating 3D representations of organs or body parts to improve understanding and treatment planning.

2. Remote Sensing

Satellite Imaging: Used for analyzing images of the Earth captured by satellites, such as monitoring land use, urban development, deforestation, and climate change.

Environmental Monitoring: Detecting changes in the environment, like changes in vegetation, pollution levels, or water quality.

Disaster Management: Analyzing aerial and satellite images to assess the damage after natural disasters (e.g., earthquakes, floods, wildfires).

3. Industrial Automation and Machine Vision

Quality Control: Automated inspection systems use image processing to check for defects in manufactured products (e.g., identifying faulty components in assembly lines).

Robot Guidance: Robots use image processing for navigation and object recognition in automated environments, such as warehouses or factories.

Barcode and OCR Recognition: Optical Character Recognition (OCR) is used for reading barcodes, serial numbers, and text in documents.

4. Face Recognition and Security

Security Systems: Digital image processing is used in surveillance systems to detect and recognize faces, helping to identify individuals or track movements.

Biometric Authentication: Used in smartphones, airports, and secure buildings for identity verification by analyzing facial features, iris scans, or fingerprints.

Access Control: Used in facial recognition systems to control access to restricted areas.

5. Entertainment and Multimedia

Photo and Video Editing: Digital image processing techniques are used in enhancing photos and videos by adjusting colors, sharpness, and contrast. Software like Photoshop and Light room rely heavily on these techniques.

Augmented Reality (AR): AR systems use image processing to overlay digital content onto real-world views. This is used in gaming, training simulations, and navigation systems.

Video Compression: Reducing the size of video files for easier storage or transmission, used in streaming platforms like Netflix or YouTube.

6. Forensic Science

Crime Scene Investigation: Image processing helps enhance images of crime scenes or security footage to reveal more details, such as identifying objects, faces, or license plates.

Fingerprint Analysis: Digital processing of fingerprint images to match prints found at a crime scene with a database of known prints.

Enhancing Evidence: Restoring degraded or obscured images (e.g., low-resolution photos) from security cameras to identify criminals or events.

7. Automated Vehicle Systems (Autonomous Vehicles)

Object Detection and Tracking: Autonomous vehicles use image processing for detecting pedestrians, other vehicles, traffic signs, and road conditions to navigate safely.

Lane Detection: Image processing algorithms help identify road markings and ensure the vehicle stays within its lane.

Traffic Monitoring: Used in traffic cameras to monitor traffic flow, detect accidents, or recognize violations (e.g., running a red light).

8. Agriculture

Crop Monitoring: Using satellite or drone images, image processing helps assess crop health, detect pests, and estimate yields.

Weed Detection: Identifying weeds in crop fields through image analysis to apply targeted herbicide treatments.

Precision Agriculture: Analyzing soil and crop images to make farming more efficient and sustainable by adjusting irrigation and fertilization.

9. Geographical Information Systems (GIS)

Topographical Mapping: Digital images are processed to create maps and terrain models for urban planning, land development, and resource management.

Urban Planning: Analyzing satellite images to study city layouts, infrastructure, and urban sprawl.

Land Use Classification: Identifying and classifying land types (e.g., forests, water bodies, urban areas) using satellite or aerial images.

10. Text Recognition and Document Processing

Optical Character Recognition (OCR): Converting scanned or photographed documents into editable text, useful for digitizing books, archives, and business documents.

Document Management: Automating the categorization, indexing, and retrieval of documents by processing and recognizing textual content in scanned images.

11. Fashion and Textile Industry

Pattern Recognition: Detecting and classifying fabric patterns, textures, and designs for quality control and production purposes.

Virtual Try-Ons: Augmented reality systems allow customers to try on clothes virtually by analyzing body shape and clothing images.

12. Sports Analysis

Performance Analysis: Coaches and analysts use video analysis to study athletes' performance, detect flaws, and improve training techniques.

Motion Tracking: Tracking players' movements on the field to analyze strategies, improve tactics, and measure performance.

13. Art and Cultural Heritage

Artwork Restoration: Enhancing or reconstructing damaged artworks or historical artifacts using image processing to bring back their original details.

Digitization of Artworks: Converting physical art objects into high-resolution digital formats for preservation and study.

Cultural Heritage Preservation: Scanning and preserving ancient manuscripts, monuments, and sculptures through digital techniques.

14. Astronomy

Astronomical Imaging: Image processing is used to enhance images of celestial objects captured by telescopes, helping to study stars, planets, galaxies, and other phenomena.

Satellite Imaging: Monitoring space phenomena and Earth from space using satellite images, which are then processed for better clarity and analysis.

15. Retail and E-Commerce

Product Recommendation Systems: Analyzing product images to categorize them and recommend similar products to customers.

Virtual Fitting Rooms: Allowing online shoppers to try on clothes or accessories using image processing and augmented reality technologies.

Digital image processing is essential in many industries, from healthcare and entertainment to security and manufacturing.

1.1.6 Types of Images

The toolbox supports four types of images:

1. Intensity images.
2. Binary images.
3. Indexed images.
4. R G B images.

Most monochrome image processing operations are carried out using binary or intensity images, so our initial focus is on these two image types. Indexed and RGB color images.

Intensity Images

An intensity image is a data matrix whose values have been scaled to represent intentions. When the elements of an intensity image are of class unit8, or class unit 16, they have integer values in the range [0,255] and [0, 65535], respectively. If the image is of class double, the values are floating point numbers. Values of scaled, double intensity images are in the range [0, 1] by convention.

Binary Images

Binary images have a very specific meaning in MATLAB.A binary image is a logical array 0s and1s.Thus, an array of 0s and 1s whose values are of data class, say unit8, is not considered as a binary image in MATLAB. A numeric array is converted to binary using function logical. Thus, if A is a numeric array consisting of 0s and 1s, we create an array B using the statement.

B=logical (A)

If A contains elements other than 0s and 1s.Use of the logical function converts all nonzero quantities to logical 1s and all entries with value 0 to logical 0s.Using relational and logical operators also creates logical arrays

Indexed Images

An indexed image has two components:

A data matrix integer, x

A color map matrix, map

Matrix map is an m*3 arrays of class double containing floating point values in the range [0, 1]. The length m of the map is equal to the number of colors it defines. Each row of map specifies the red, green and blue components of a single color. An indexed images uses “direct mapping” of pixel intensity values color map values. The color of each pixel is determined by using the corresponding value the integer matrix x as a pointer in to map. If x is of class double, then all of its components with values less than or equal to 1 point to the first row in map, all components with value 2 point to the second row and so on. If x is of class units or unit 16, then all components value 0 point to the first row in map, all components with value 1 point to the second and so on.

RGB Image

An RGB color image is an M*N*3 array of color pixels where each color pixel is triplet corresponding to the red, green and blue components of an RGB image, at a specific spatial location. An RGB image may be viewed as “stack” of three gray scale images that when fed in to the red, green and blue inputs of a color monitor

Produce a color image on the screen. Convention the three images forming an RGB color image are referred to as the red, green and blue components images. The data class of the components images determines their range of values. If an RGB image is of class double the range of values is [0, 1].

Similarly the range of values is [0,255] or [0, 65535].For RGB images of class units or unit 16 respectively. The number of bits use to represents the pixel values of the component images determines the bit depth of an RGB image. For example, if each component image is an 8bit image, the corresponding RGB image is said to be 24 bits deep.

Generally, the number of bits in all component images is the same. In this case the number of possible color in an RGB image is (2^b) ^3, where b is a number of bits in each component image. For the 8bit case the number is 16,777,216 colors

CHAPTER 2

LITERATURE SURVEY

Underwater image enhancement is a critical area of research aimed at improving the visual quality of images captured in underwater environments. The challenges inherent in underwater imaging, such as color distortion, low contrast, and blurring, necessitate the development of effective enhancement techniques. Various methodologies have been proposed to address these issues, which can be broadly categorized into physical model-based methods, non-physical model-based methods, and deep learning-based methods.

Physical model-based methods are characterized by their reliance on understanding and modeling the fundamental principles of underwater image formation. These techniques often involve estimating parameters such as light transmission, backscatter, and scene depth to compensate for the effects of light attenuation and scattering in water. While these methods can provide robust enhancement, they often require precise estimation of complex underwater image parameters, which can limit their applicability across diverse underwater conditions.

Non-physical model-based methods, in contrast, employ traditional image processing techniques to enhance underwater images. These methods focus on manipulating pixel values to improve visual attributes such as contrast, color balance, and sharpness. Techniques such as histogram equalization, color correction, and Retinex algorithms fall under this category. While computationally efficient, these methods may lack the generalization capability to handle the complexities of underwater image degradation due to their limited consideration of the underlying physical processes.

The advent of deep learning has led to the development of deep learning-based methods for underwater image enhancement. These methods leverage the learning capacity of neural networks to learn complex mappings between degraded and enhanced images. Deep learning approaches have demonstrated promising results but often require large datasets for training, and their performance can be constrained by the availability and representativeness of real-world underwater image data. Furthermore, the generalization of deep learning models can be limited when applied to underwater images that differ significantly from the training data.

In response to the limitations of existing techniques, particularly the generalization challenges of non-physical model-based methods, recent research has explored hybrid approaches. These approaches often combine elements from different categories to achieve more robust and effective underwater image enhancement.

CHAPTER 3

EXISTING METHODS

Underwater image restoration using depth map estimation. Image blurriness is used as a before acquiring a depth map. As depth increases, image blurriness also gets increased. Here backlight is retrieved from the largest blurriness region and lowest variance region. A backlight is estimated from the top brightest pixel. If artificial lighting is used for illumination, foreground objects appear to be brighter than background objects. So, selecting the brightest pixels may lead to erroneous results. Then substituting backlight and depth map in IFM scene radiance is restored.

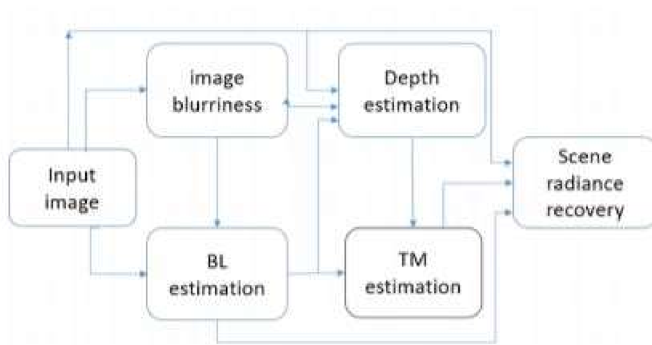


Fig 3.1: *Existing Method*

Input Image

The enhancement process begins with the input image, which represents the raw, unprocessed underwater capture. This image is the starting point and typically exhibits the characteristic degradations of underwater scenes, including color distortion dominated by blue-green hues, reduced contrast that obscures details, and the presence of noise that can obscure clarity. The goal of the subsequent steps is to transform this degraded input image into a visually improved output.

Image Blurriness Estimation

A crucial step in some underwater enhancement methods is the estimation of image blurriness. This process aims to quantify the degree of blurring present in different regions of the input image. Various techniques can be employed, analyzing image energy, edge sharpness, pixel intensity distribution, and local gradient variations. The output of this stage is a blurriness map, where each value corresponds to the level of blur at that specific location in the image. This information can be valuable for tasks like depth estimation or selective enhancement.

Backlight Estimation

Underwater images are often affected by backlight, a phenomenon where light is scattered by particles in the water, creating a hazy appearance. Backlight estimation seeks to determine the intensity and color of this ambient light. This can involve analyzing regions of low variance and high blurriness, as well as considering the brightest areas of the image. Accurate backlight estimation is critical for compensating for its adverse effects and improving image contrast and visibility.

Depth Estimation

In certain enhancement approaches, estimating the depth of objects within the underwater scene is a key component. This depth estimation can be achieved through various cues, such as the attenuation of red light, the differential attenuation of color channels, and the degree of image blurriness. By combining these different depth cues, a depth map can be generated, providing an estimate of the distance of various image elements from the camera. This depth information can be leveraged to improve the accuracy of restoration processes.

Scene Radiance Recovery

The ultimate objective of many underwater image enhancement methods is to recover the original scene radiance. This involves using the estimated parameters, such as backlight and depth, to compensate for the effects of water on light propagation. Models like the Beer-Lambert law, which describes light attenuation, are often employed to reverse the degradation and restore a clearer, more accurate representation of the underwater environment. This step aims to produce an enhanced image that is closer to how the scene would appear in clear air.

The existing methods for underwater image enhancement using adaptive color correction and improved Retinex algorithm are:

Physical Model-Based Methods: These methods establish underwater image enhancement models by studying the distortion principle of underwater images.

Non-Physical Model-Based Methods: These methods utilize traditional image processing techniques to enhance underwater images.

Deep Learning-Based Methods: These methods use the powerful learning ability of deep learning to enhance underwater images.

CHAPTER 4

PROPOSED METHOD

This project addresses the limitation of weak generalization in non-physical model-based methods for underwater image enhancement. To overcome this, we introduce an adaptive underwater image enhancement method designed to perform effectively with complex underwater images, drawing inspiration from the work.

Our method employs a combination of color correction, contrast enhancement, tone adjustment, and image fusion techniques to achieve improved underwater image enhancement.

The proposed algorithm demonstrates enhanced performance compared to contrast algorithms, as validated by evaluations using PCQI, UCIQE, UIQM, and IE metrics.

A key contribution is an adaptive color correction method, specifically developed to effectively remove color cast from underwater images, a common issue in complex underwater environments.

This project also introduces an improved Retinex algorithm, designed to adaptively adjust the tone of underwater images, effectively enhancing both dark and bright images to produce more visually pleasing results.

4.1 Workflow of Underwater Image Enhancement

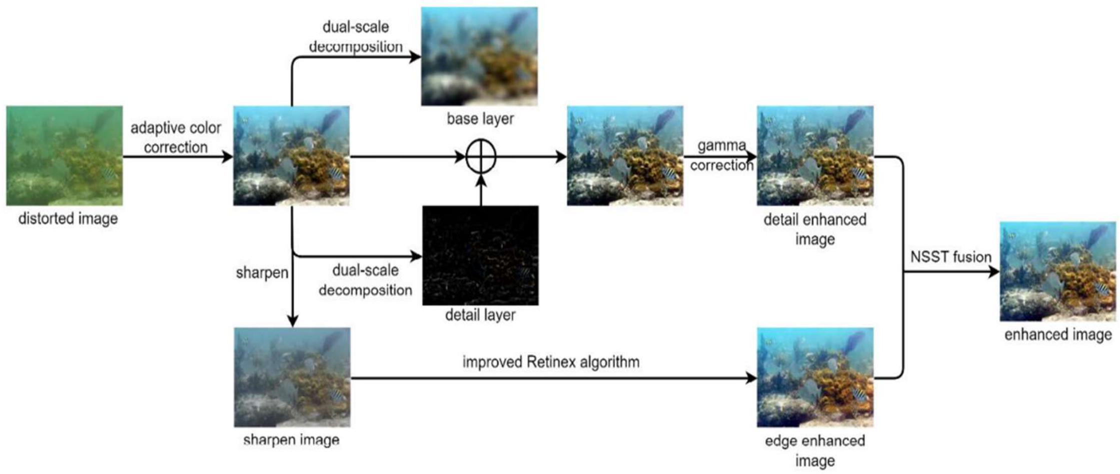


Fig 4.1 *Workflow of Underwater Image Enhancement Process*

We firstly perform the adaptive color correction method on underwater distorted images in order to deal with the color bias phenomenon. Then on the one hand, the dual-scale image decomposition and Gamma correction are used to yield a detail enhanced image. On the other hand, the sharpen algorithm and the improved Retinex algorithm are used to adjust the hue of the image to produce an edge enhanced image. Finally, based on NSST technique, we fuse the detail enhanced image and the edge enhanced image to obtain the final enhanced underwater image.

Additionally, our method effectively suppresses the backscattering effect, which often causes haze-like degradation in underwater images. The improved Retinex algorithm ensures better illumination correction, preserving natural color tones while enhancing visibility. Furthermore, the NSST-based fusion technique retains essential structural details, leading to a more visually appealing and informative output.

4.2 Steps In Processing Underwater Images

Fig 4.2(a) Underwater Image with Color Distortion.

Fig 4.2(b) Underwater Image Enhancement Process

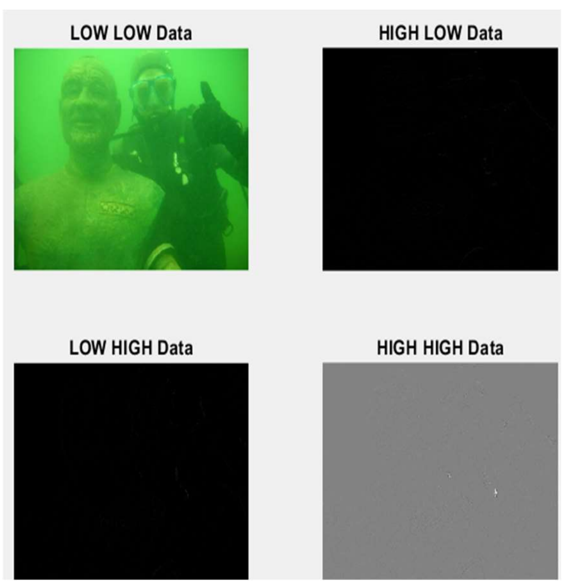


Fig 4.2(c) (DWT) Decomposition

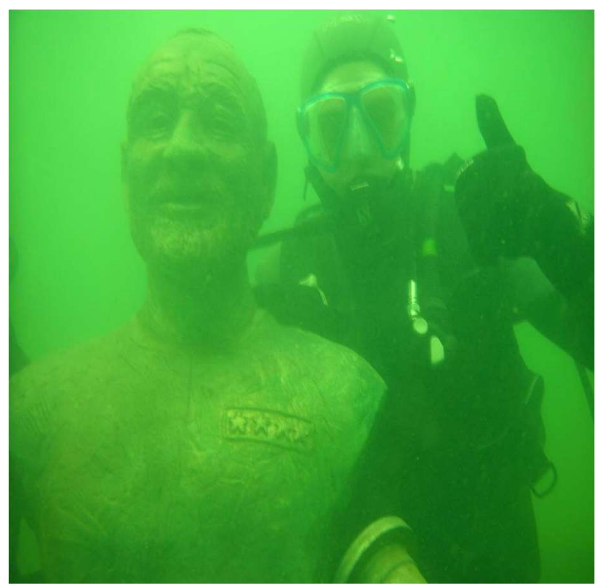


Fig 4.2(d) DWT Processed Image

Fig 4.2(e) Retinex Enhanced Image

4.2(f) Fusion-Based Retinex Processed Image

4.2.1 Adaptive Color Correction

This method is designed to address the color distortion commonly found in underwater images, which is primarily caused by the absorption of light as it travels through water. To achieve this, the method adaptively adjusts the intensities of the red, green, and blue (RGB) color channels of the image. The process involves first extracting the individual RGB channels and then computing the mean intensity of each. Following this, each channel is adjusted based on its intensity relative to the others. Channel compensation is then applied to balance the colors across the image. Finally, the corrected color channels are merged to produce the final color-corrected image.

4.2.2 Dual-Scale Decomposition

This technique serves to decompose an image into two distinct layers: a base layer and a detail layer. The base layer represents the smooth components of the image, while the detail layer contains its sharper features. By separating the image in this way, it becomes possible to enhance the finer details while, at the same time, preserving the overall smoothness of the image. The process begins with converting the image to grayscale. A large-scale Gaussian filter is then applied to extract the base layer. The detail layer is obtained by subtracting the base layer from the original image. To enhance sharpness, the detail layer is reintroduced into the image.

4.2.3 Gamma Correction

Gamma correction is employed to adjust the brightness of an image in a non-linear manner, which is particularly useful for enhancing the visibility of darker regions in underwater scenes. This adjustment also aids in improving the image's contrast while preventing overexposure in brighter areas. The procedure involves selecting an appropriate gamma value, applying the gamma correction formula to the image's pixels, and adjusting the brightness accordingly.

4.2.4 Retinex Processing

Retinex processing is a technique used to enhance contrast and edges in images, with the goal of mimicking the way human vision adapts to varying illumination conditions. It also works to reduce the impact of uneven illumination across the image. Initially, the image is converted to grayscale. Then, a Gaussian blur is applied to simulate the background illumination. Following this, the Retinex transformation is computed using logarithms. Finally, histogram stretching is used to enhance the image's contrast.

4.2.5 Final Image Fusion

The final image fusion step aims to merge the most desirable features from two enhanced images: one that has been detail-enhanced and the other Retinex-enhanced. This process seeks to create a final image that benefits from the strengths of both enhancement techniques. The Non-Subsampled Shearlet Transform (NSST) is utilized to facilitate this fusion. The process involves converting both enhanced images to the LAB color space. Saliency weights are calculated to guide the blending of the images. The final fusion is achieved by computing a weighted sum of the images, using the saliency weights to determine the contribution of each image.

4.3 Table of Proposed Enhancement Process

Step	**Purpose**	**Key Technique**
Adaptive Color Correction	Fixes color imbalance	RGB Channel Compensation
Dual-Scale Decomposition	Enhances details	Gaussian Filtering
Gamma Correction	Adjusts brightness	Power-Law Transformation
Retinex Processing	Improves contrast & edges	Logarithmic Transformation
Final Image Fusion	Merges best features	Weighted Sum Blending

4.4 Underwater Image Quality Metrics

Underwater image enhancement techniques are evaluated using a range of quality metrics to objectively assess their performance. The following sections detail four commonly used metrics: PCIQ, UCIQE, UIQM, and IE, along with their definitions, ideal value ranges, and the formulas used in their calculation.

4.4.1 PCIQ (Perceptual Color Image Quality)

PCIQ measures the preservation and balance of colors in an enhanced image. It considers contrast and noise to ensure that the resulting colors appear natural and visually pleasing.

Ideal Range: 0.5 to 1.0

- Values closer to 1 indicate superior color preservation and contrast.
- Values below 0.5 suggest inadequate color correction, faded colors, or excessive noise.

4.4.2 UCIQE (Underwater Color Image Quality Evaluation)

UCIQE is a specialized metric designed for underwater images. It evaluates chroma (color spread and saturation), luminance contrast, and image sharpness to determine the image's clarity and natural appearance.

Ideal Range: 5 to 20

- A higher UCIQE value (>10) indicates better contrast, more vivid colors, and improved visibility.
- A UCIQE value below 5 suggests that the image may still exhibit blurriness or haze.

4.4.3 UIQM (Underwater Image Quality Measure)

UIQM is a composite metric that assesses the overall visual quality of an underwater image by considering colorfulness (UICM), sharpness (UISM), and contrast (UIConM).

Ideal Range: 10 to 40

- A higher UIQM value (>25) signifies a well-enhanced image with good sharpness and color balance.
- A UIQM value below 10 indicates that the image remains hazy, blurry, or lacks sufficient contrast.

4.4.4 IE (Image Entropy)

Image Entropy (IE) quantifies the amount of information present in an image. Higher entropy corresponds to greater detail preservation and contrast.

Ideal Range: Higher is better

A high entropy value (>6) suggests a well-enhanced image with rich details.

A low entropy value (<4) implies that the image is blurry or lacks sharpness.

Figure 4.3 *Image Quality Matrix*

4.5 Table of Ideal Ranges of Metric Values

Metric	Definition	Ideal Range	Best Values
PCIQ	Color quality	0.5 - 1.0	Closer to 1
UCIQE	Underwater clarity	5 - 20	>10 for better clarity
UIQM	Overall quality	10 - 40	>25 for better sharpness
IE	Image details	Higher is better	>6 preferred

Conclusion

These quality metrics play a crucial role in evaluating the effectiveness of underwater image enhancement techniques. An optimally enhanced image should ideally exhibit the following characteristics:

- PCIQ values close to 1, indicating good color balance.
- UCIQE values exceeding 10, indicating improved underwater visibility.
- UIQM values greater than 25, reflecting enhanced sharpness and contrast.
- IE values greater than 6, signifying rich details and clarity.

CHAPTER 5

SOFTWARE DETAILS

5.1 Introduction to MATLAB

The name MATLAB stands for Matrix Laboratory. The software is built up around vectors and matrices. This makes the software particularly useful for linear algebra but MATLAB is also a great tool for solving algebraic and differential equations and for numerical integration. MATLAB has powerful graphic tools and can produce nice pictures in both 2D and 3D. It is also a programming language, and is one of the easiest programming languages for writing mathematical programs. These factors make MATLAB an excellent tool for teaching and research.

MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. MATLAB has many advantages compared to conventional computer languages (e.g., C, FORTRAN) for solving technical problems.

MATLAB abilities a family of add-on software program utility software application software program software utility software-unique solutions called toolboxes. Very essential to maximum customers of MATLAB, toolboxes assist you to studies and observe specialized technology. Toolboxes are entire collections of MATLAB abilities (M-files) that increase the MATLAB surroundings to remedy precise schooling of problems. Areas in which toolboxes are to be had embody signal processing, manipulate systems, neural networks, fuzzy correct judgment, wavelets, simulation, and hundreds of others. It has powerful built-in routines that enable a very wide variety of computations. It also has easy to use graphics commands that make the visualization of results immediately available. Specific applications are collected in packages referred to as toolbox. There are toolboxes for signal processing, symbolic computation, control theory, simulation, optimization, and several other fields of applied science and engineering. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered as a standard tool at most universities and industries worldwide.

5.2 Stating MATLAB

After logging into your account, you can enter MATLAB by double clicking on the MATLAB shortcut icon (MATLAB 7.0.4) on your Windows desktop. When you start MATLAB, a special window called the MATLAB desktop appears. The desktop is a window that contains other windows. The major tools within or accessible from the desktop are:

5.2.1 Current Folder

This panel allows you to access the project folders and files.

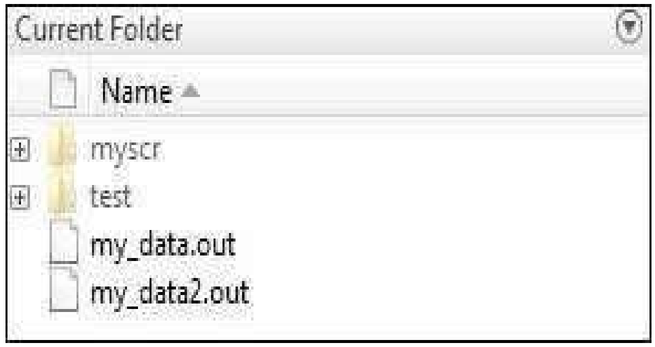


Figure 5.1 : Current Folder

5.2.2 Command Window

This is the main area where commands can be entered at the command line. It is indicated by the command prompt (>>).

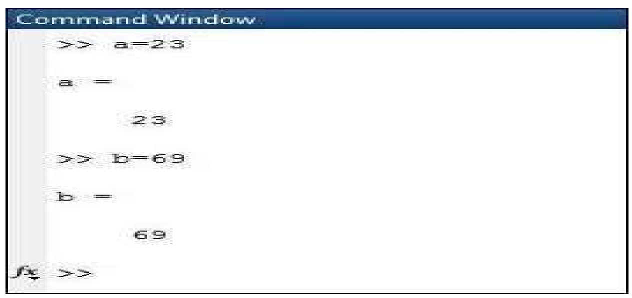
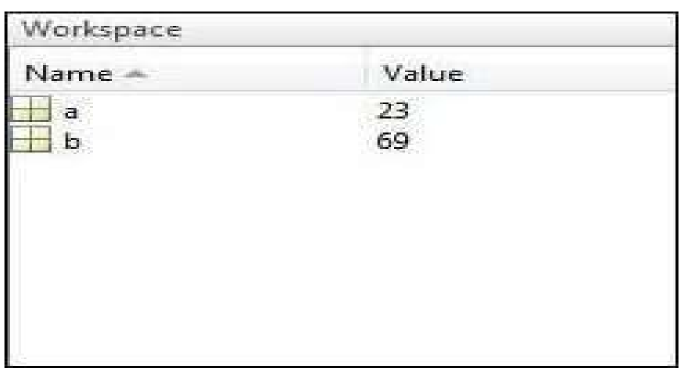


Figure 5.2: Command Window

5.2.3 Workspace



The workspace shows all the variables created and/or imported from files.

Figure 5.3: Workspace

5.2.4 Command History

This panel shows or return commands that are entered at the command line.

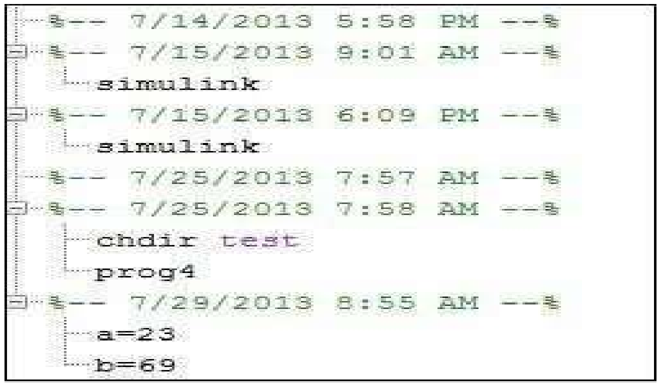


Figure 5.4: Command History

5.2.5 Help Browser

The critical way to get assist online is to use the MATLAB help browser, opened as a separate window every through clicking at the question mark photograph (?) on the computing tool toolbar, or through manner of typing assist browser on the spark off in the command window.

The assist Browser is an internet browser blanketed into the MATLAB computing tool that shows a Hypertext Markup Language (HTML) file. The Help Browser consists of panes, the help navigator pane, used to find out information, and the show pane, used to view the information. Self-explanatory tabs apart from navigator pane are used to performs are searching out.

5.2.6 MATLAB language

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create complete large and complex application programs.

5.2.7 MATLAB working environment

This is the set of tools and facilities that you work with as the MATLAB user or programmer.

It includes facilities for managing the variables in your workspace and importing and exporting data.

It also includes tools for developing, managing, debugging, and profiling M-files, MATLAB's applications.

5.2.8 MATLAB mathematical function library

This is a vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

5.2.9 MATLAB Application Program Interface (API)

This is a library that allows you to write C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from

MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

5.3 Using the MATLAB Editor to create M-Files

The MATLAB editorial manager is a literary substance proofreader particular for growing M-facts and a graphical MATLAB debugger.

The supervisor can seem in a window through command facts technique for itself, or it is probably a right-clicking inside the PC. M- Information this gadget signified through the use of the expansion .M, as in pixel up.M.

The MATLAB editorial supervisor window has a few draws down menus for obligations collectively with sparing, seeing, and troubleshooting facts. Since it plays more than one easy test and furthermore affects utilization of shade to separate among exclusive variables of code, this article editorial supervisor is often supported due to reality the system of a need for composing and altering M-talents. To open the manager, type at enact opens the M-document filename. M in a supervisor window, sorted out for enhancing. As stated earlier than, the file should be inside the cutting-edge posting, or in a posting in the seeking out direction.

5.3.1 Features of MATLAB

Following are the basic features of MATLAB.

- It is a high-level language for numerical computation, visualization and application development.
- It also provides an interactive environment for iterative exploration, design and problem solving.
- It provides vast library of mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, numerical integration and solving ordinary differential equations.
- It provides built-in graphics for visualizing data and tools for creating custom plots.
- MATLAB's programming interface gives development tools for improving code quality maintainability and maximizing performance.
- It provides tools for building applications with custom graphical interfaces.
- It provides functions for integrating MATLAB based algorithms with

external applications and languages such as C, Java,

- .NET and Microsoft Excel.

5.3.2 Uses of MATLAB

MATLAB is widely used as a computational tool in science and engineering encompassing the fields of physics, chemistry, math and all engineering streams. It is used in a range of applications including

- Signal Processing and Communications
- Video and Video Processing
- Control Systems
- Test and Measurement
- Computational Finance
- Computational Biology

5.3.3 Applications of MATLAB

MATLAB can be used as a tool for simulating various electrical networks but the recent developments in MATLAB make it a very competitive tool for Artificial Intelligence, Robotics, Video processing, Wireless communication, Machine learning, Data analytics and whatnot. Though it's mostly used by circuit branches and mechanical in the engineering domain to solve a basic set of problems its application is vast.

It is a tool that enables computation, programming and graphically visualizing the results. The basic data element of MATLAB as the name suggests is the Matrix or an array.

MATLAB toolboxes are professionally built and enable you to turn your imaginations into reality. MATLAB programming is quite similar to C programming and just requires a little brush up of your basic programming skills to start working with.

Below are a few applications of MATLAB –

Statistics and machine learning (ML)

This toolbox in MATLAB can be very handy for the programmers Statistical methods such as descriptive or inferential can be easily implemented. So is the case with machine learning. Various models can be employed to solve modern-day problems. The algorithms used can also be used for big data applications.

Curve fitting

The curve fitting toolbox helps to analyze the pattern of occurrence of data. After a particular trend which can be a curve or surface is obtained, its future trends can be predicted. Further plotting, calculating integrals, derivatives, interpolation, etc. can be done.

Control systems

Systems nature can be obtained. Factors such as closed-loop, open- loop, its controllability and observability, Bode plot, NY Quist plot, etc. can be obtained. Various controlling techniques such as PD, PI and PID can be visualized. Analysis can be done in the time domain or frequency domain.

Signal Processing

Signals and systems and digital signal processing taught in various engineering streams. But MATLAB provides the opportunity for proper visualization of this. Various transforms such as Laplace, Z, etc. can be done on any given signal. Theorems can be validated. Analysis can be done in the time domain or frequency domain. There are multiple built-in functions that can be used.

Mapping

Mapping has multiple applications in various domains. For example, in Big Data, the Map Reduce tool is quite important which has multiple applications in the real world. Theft analysis or financial fraud detection, regression models, contingency analysis, predicting techniques in social media, data monitoring, etc. can be done by data mapping.

Deep learning

It's a subclass of machine learning which can be used for speech recognition, financial fraud detection, and medical video analysis. Tools such as time-series, Artificial neural network (ANN), Fuzzy logic or combination of such tools can be employed.

Financial analysis

An entrepreneur before starting any endeavor needs to do a proper survey and the financial analysis in order to plan the course of action. The tools needed for this are all available in MATLAB. Elements such as profitability, solvency, liquidity, and stability can be identified. Business valuation, capital budgeting, cost of capital, etc. can be evaluated.

Video processing

The most common application that we observe almost every day are bar code scanners, selfie (face beauty, blurring the background, face detection), video enhancement, etc. The digital video processing also plays quite an important role in transmitting data from far off satellites and receiving and decoding it in the same way. Algorithms to support all such applications are available.

Text analysis

Based on the text, sentiment analysis can be done. Google gives millions of search results for any text entered within a few milliseconds. All this is possible because of text analysis. Handwriting comparison in forensics can be done. No limit to the application and just one software which can do this all.

Electric vehicles designing

Used for modeling electric vehicles and analyze their performance with a change in system inputs. Speed torque comparison, designing and simulating of a vehicle, whatnot.

Aerospace

This toolbox in MATLAB is used for analyzing the navigation and to visualize flight simulator.

Audio toolbox

Provides tools for audio processing, speech analysis, and acoustic measurement. It also provides algorithms for audio and speech feature extraction and audio signal transformation.

Communication

Communications System Toolbox™ offers algorithms and gear for the layout, simulation, and analysis of communications systems. These capabilities are furnished as MATLAB ® features, MATLAB System gadgets™, and Simulink ® blocks. The machine toolbox includes algorithms for source coding, channel coding, interleaving, modulation, equalization, synchronization, and channel modeling.

Tools are supplied for bit blunders charge evaluation, producing eye and constellation diagrams, and visualizing channel characteristics. The machine toolbox additionally provides adaptive algorithms that allow you to version dynamic communications structures that use OFDM, OFDMA, and MIMO techniques. Algorithms support fixed-point facts arithmetic and C or HDL code era.

5.3.4 Key Features

Algorithms for designing the physical layer of communications systems, which includes supply coding, channel coding, interleaving, modulation, channel fashions, MIMO, equalization, and synchronization

GPU-enabled System objects for computationally intensive algorithms together with Turbo, LDPC, and Viterbi

Decoders

Interactive visualization equipment, consisting of eye diagrams, constellations, and channel scattering capabilities

Graphical tool for evaluating the simulated bit mistakes rate of a machine with **analytical outcomes**

Channel models, consisting of AWGN, Multipath Rayleigh Fading, Rician Fading, MIMO Multipath Fading, and

LTE MIMO Multipath Fading

Basic RF impairments, along with nonlinearity, section noise, thermal noise, and section and frequency offsets

Algorithms available as MATLAB features, MATLAB System objects, and Simulink blocks

Support for fixed-point modeling and C and HDL code technology.

CHAPTER 6

ADVANTAGES AND APPLICATIONS

6.1 Advantages

1. **Addresses Underwater Image Degradation:** The algorithm tackles the common problems of underwater images, including color distortion, low contrast, and blurring, leading to more visually appealing and informative images.
2. **Adaptive Color Correction:** The method includes an adaptive color correction technique that effectively removes color casts, which are prevalent due to the selective absorption of light in water.
3. **Improved Retinex Algorithm:** The enhancement uses an improved Retinex algorithm to adjust the tone of underwater images, correcting images that are either too dark or too bright.
4. **Detail and Edge Enhancement:** The algorithm enhances both the fine details and edges within underwater images, providing sharper and clearer visuals.
5. **Quantitative Performance:** The method's effectiveness is supported by quantitative evaluations, showing improved results in PCQI, UCIQE, UIQM, and IE metrics compared to other enhancement techniques.
6. **Robustness:** The algorithm demonstrates robustness in handling complex underwater environments.
7. **Single-Image Enhancement:** The algorithm is designed as a single-image enhancement method, which means it does not require specialized equipment or prior knowledge of the underwater scene, making it more versatile and easier to implement.

6.2 Applications

Enhancing Underwater Vision Systems: The algorithm can be integrated into underwater vision systems to improve the clarity of captured images, which is crucial for underwater robots and other automated systems.

Supporting Underwater Vehicle Control: By providing clearer images, the algorithm aids in the development and operation of underwater vehicles, improving their navigation and manipulation capabilities.

Aiding Underwater Infrastructure Inspection: The enhanced images can be used to inspect underwater structures such as pipelines, bridges, and offshore platforms, making the inspection process more accurate and efficient.

Advancing Marine Biological Research: The algorithm can play a significant role in marine biology research by improving the visualization of marine organisms and habitats, enabling scientists to study and monitor marine life more effectively.

Supporting Ocean Exploration: The enhancement of underwater images contributes to the broader field of ocean exploration, allowing for better documentation and analysis of underwater environments.

CHAPTER 7

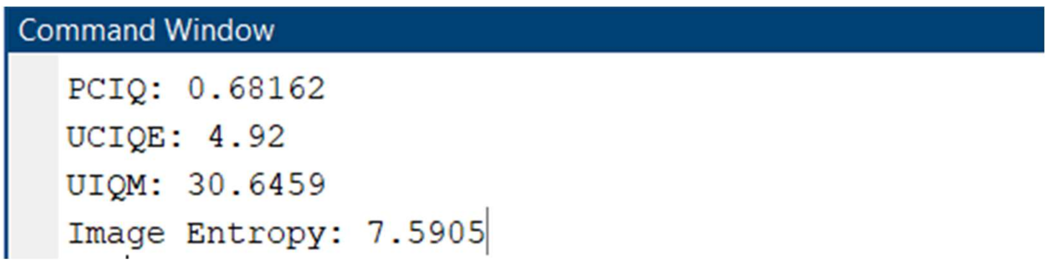
RESULTS

7.1 Comparison

Input Image ***Resulted Image***

A set of paired images visually demonstrates the underwater image enhancement process. The left image of each pair represents the original, distorted underwater image, typically exhibiting color cast, low contrast, and blurring. The corresponding right image showcases the result of applying the adaptive color correction and improved Retinex algorithm, highlighting the enhancement in color fidelity, contrast, and sharpness.

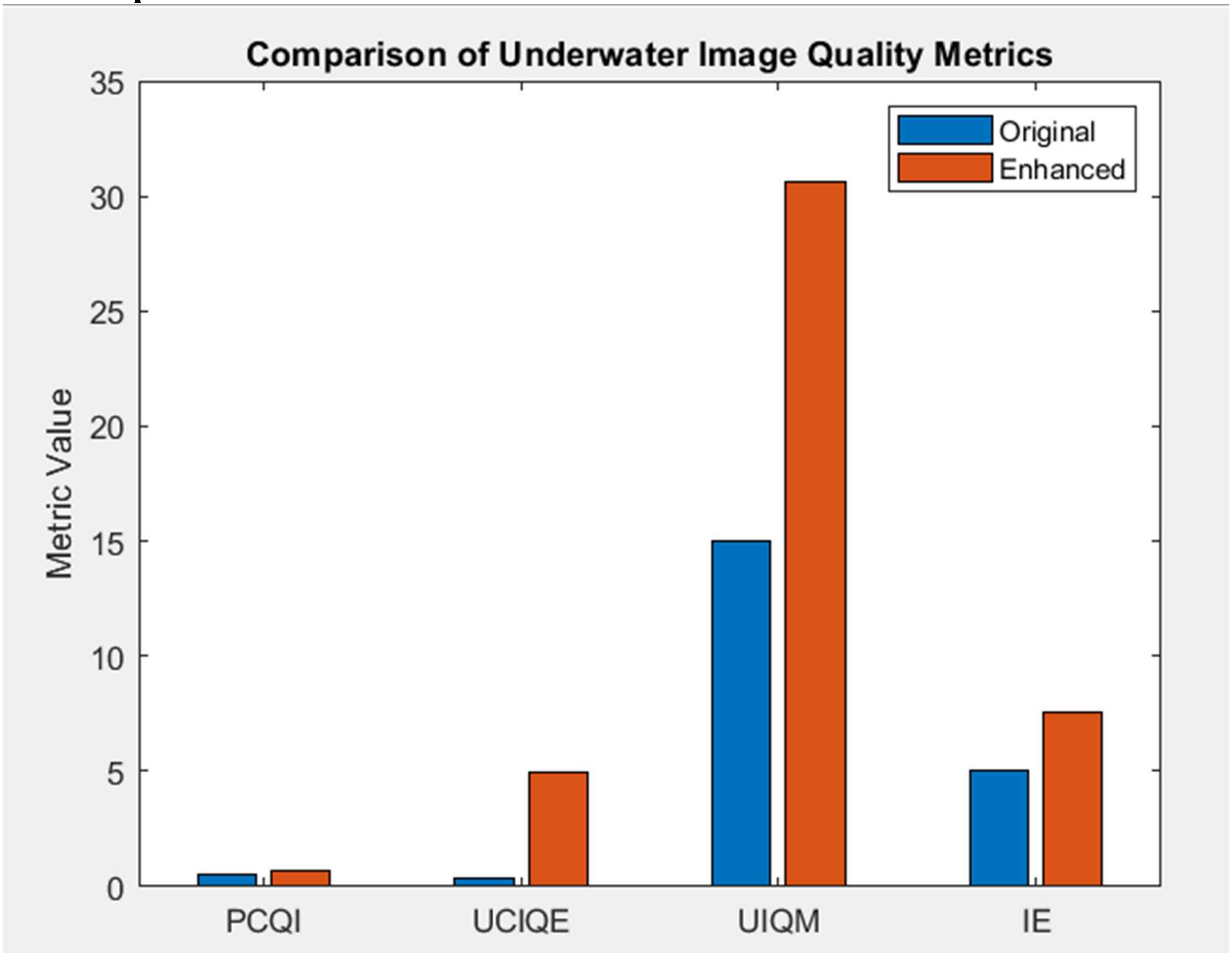
7.2 Image Quality Metrics Values


Command Window

```
PCIQ: 0.68162
UCIQE: 4.92
UIQM: 30.6459
Image Entropy: 7.5905
```

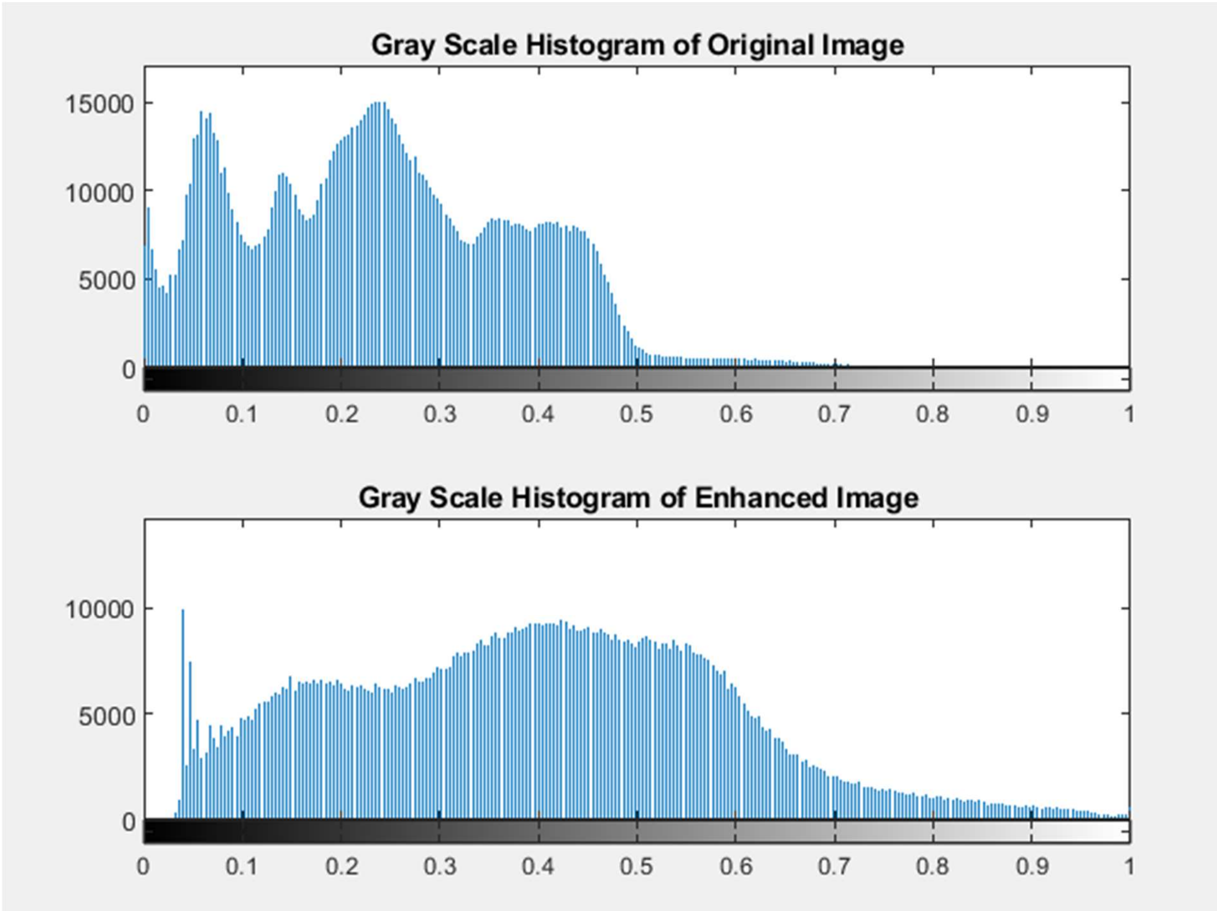
The results also represents a table of computed metric values**,** including **PCIQ** (Perceptual Color Image Quality), **UCIQE** (Underwater Color Image Quality Evaluator), **UIQM** (Underwater Image Quality Measure), and **IE** Image Entropy**.** These values serve as objective measures to quantify the improvement in image quality after enhancement, providing insight into the effectiveness of the applied algorithm.

7.3 Graph of Metric Values



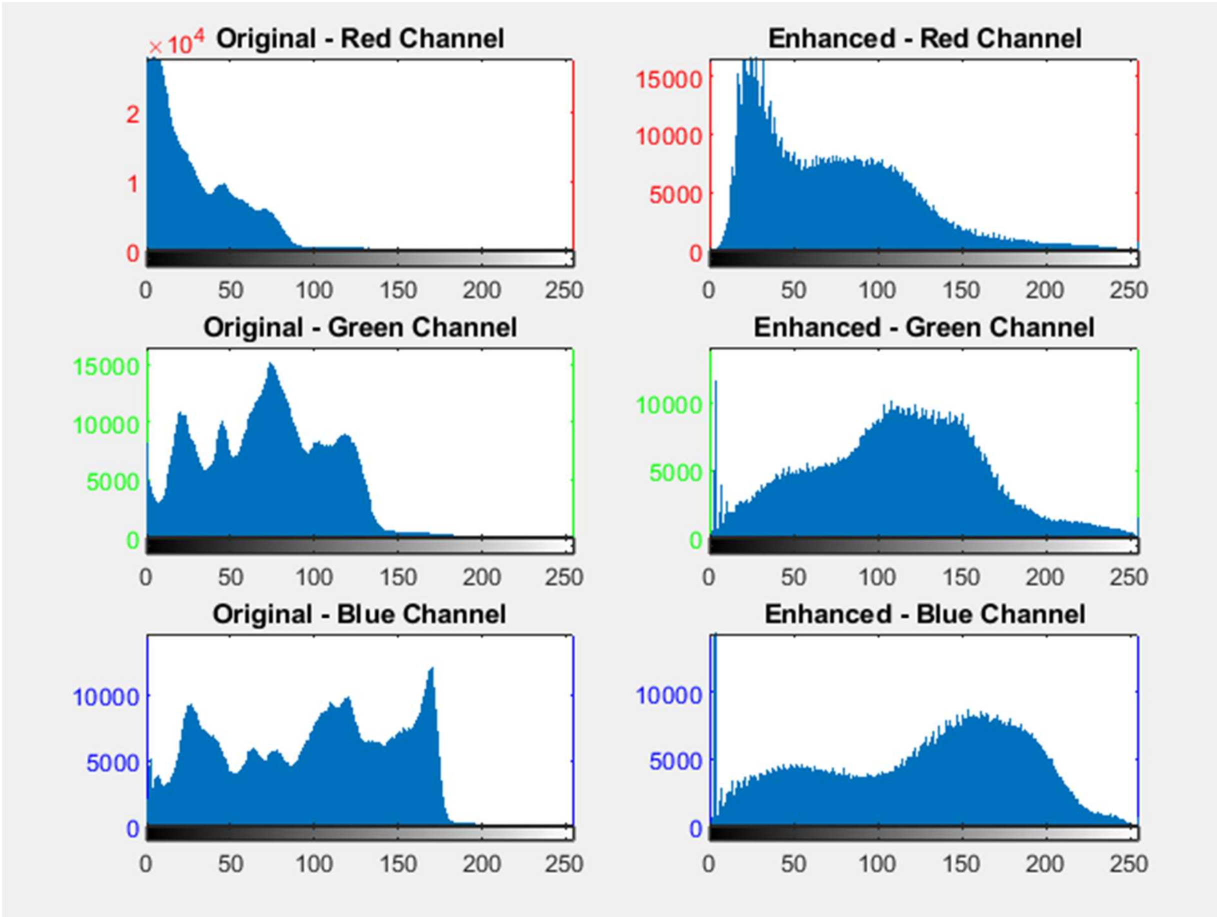
A grayscale histogram is included to compare the intensity distribution of the original and enhanced images. This histogram helps illustrate changes in contrast and brightness, showing how the enhancement process affects the overall tonal balance of the images.

7.4 Grayscale Histograms



A pair of grayscale histograms provides insight into the image's intensity distribution before and after enhancement. The original image's histogram often reveals a limited range of intensity values, indicative of low contrast, while the enhanced image's histogram demonstrates a broader distribution, signifying improved contrast and detail.

7.5 RGB Histogram



A set of RGB histograms compares the color channel distribution of the original and enhanced images. These histograms illustrate how the enhancement algorithm alters the intensity of red, green, and blue pixels, showcasing the correction of color imbalances and the expansion of the color range.

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

8.1 CONCLUSION

The complex underwater environment causes the problems about color distortion, low contrast and image blur. Aiming at these phenomena, we propose an underwater image enhancement algorithm based on adaptive color correction and improved Retinex algorithm. The designed adaptive color correction algorithm can effectively remove various color distortion. The improved Retinex algorithm can enhance the details and edges of the color corrected image. The detail enhanced image and the edge enhanced image are fused through NSST to produce the final enhanced image.

8.2 FUTURE SCOPE

- **AI & Deep Learning Integration:**

  - CNNs and GANs for automated image enhancement.
  - AI-driven self-learning models for adaptive enhancement.
  - Automated feature extraction for marine research.

- **Real-Time Processing for AUVs & Robotics:**

  - Faster adaptive enhancement algorithms for underwater drones.
  - GPU & FPGA acceleration for real-time processing.
  - Navigation improvement for deep-sea exploration.

- **Multispectral & Hyperspectral Imaging:**

  - Enhancing images beyond RGB using multiple spectral bands.

- Adaptive filtering for different wavelengths.
- Applications in oceanography and marine species detection.

- **Enhancing Visibility in Extreme Conditions:**
  - Adaptive correction based on water turbidity and depth.
  - Fusion of image data with sonar and Lidar for improved visibility.
  - Improved Retinex models to reduce noise in low-light conditions.

- **Surveillance & Security Applications:**
  - Naval and military surveillance enhancement.
  - Detection of underwater threats (mines, submarines, illegal activities).
  - Search and rescue operations using AI-enhanced imaging.

- **Medical & Bio-Research Applications:**
  - High-resolution underwater imaging for deep-sea microbiology.
  - Potential applications in marine life research and environmental monitoring.
  - Study of deep-sea organisms for medical discoveries.

- **Cloud & Edge Computing for Image Processing:**
  - Cloud-based remote processing of underwater images.
  - Edge computing on underwater drones for autonomous enhancement.
  - Reducing dependence on heavy computing resources.

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