A Project Report on

UNDER WATER IMAGE ENHANCEMENT TECHNIQUES AND IMAGE RESTORATION

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Submitted to the Department of Computer Science & Engineering, GNITS in the partial fulfillment of the academic requirement for the award of B.Tech (CSE) under JNTUH

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Certificate

This is to certify that the Project report on “**Underwater Image enhancement Techniques and Image Restoration**” is a bonafide work carried out by **D.Sushma (17251A0566), P.Dhatri Reddy (17251A0583), M.Sujitha (17251A05A9) and P.Priyanka (18255A0519)** in the partial fulfillment for the award of B.Tech degree in Computer Science & Engineering, G. Narayanamma Institute of Technology & Science, Shaikpet, Hyderabad, affiliated to Jawaharlal Nehru Technological University, Hyderabad under our guidance and supervision.

The results embodied in the project work have not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

The oceans contain unknown creatures and vast energy resources, playing an important role in the continuation of life on earth. Since the middle of the 20th century, marine exploration worldwide has actively engaged in high-tech activities. But, the quality of underwater images is severely affected by the particular physical and chemical characteristics of underwater conditions, raising issues that are more easily overcome in terrestrial imaging. Underwater images also show color cast, which is caused by different attenuation ratios of red, green and blue lights.

The existing system requires the parameters of underwater imaging model estimation or use inflexible frameworks which are applicable only for specific scenarios. Like Gray-Edge Assumption (GEA) as color correction methods to modify color and saturation of the images but GEA often fails to enhance the images as the contrast of underwater images is low and the edge features are hazed.

The proposed method is an Unsupervised Color Correction Method (UCM) for underwater image enhancement. UCM is based on color balancing, contrast correction of RGB color model and contrast correction of HSI color model. Firstly, the color cast is reduced by equalizing color values. Then an enhancement toa contrast correction method is applied to increase the Red color by stretching red histogram towards the maximum similarly the Blue color is reduced by stretching the blue histogram towards the minimum. Then, the Saturation and Intensity components of the HSI color model have been applied for contrast correction to increase the true color using Saturation and to address the illumination problem through Intensity.

KEYWORDS: Unsupervised Color Correction Method (UCM), underwater image enhancement, RGB, HSI

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1. INTRODUCTION

The oceans contain unknown creatures and vast energy resources, playing an important role in the continuation of life on earth Since the middle of the 20th century, marine exploration worldwide has actively engaged in high-tech activities Vision technology has attracted great attention, for its ability to carry high information density Researchers strive to capture high-quality underwater images for a variety of underwater applications, including robotics Rescue missions, man-made structures inspection, ecological monitoring, sea organisms tracking and real-time navigation. However, the quality of underwater images is severely affected by the particular physical and chemical characteristics of underwater conditions, raising issues that are more easily overcome in terrestrial imaging

Underwater images always show color cast, e.g., green bluish color, which is caused by different attenuation ratios of red, green and blue lights

Background Study

Light undergoes attenuation when it is passed through water. The larger wavelengths are affected more when compared to the shorter wavelengths, thus, images captured underwater appear greenish blue as they lack certain wavelength components extensively. For instance an image acquired at a depth of about 4 -5m underwater will lack red wavelength because the longer wavelength components of the visible spectrum is attenuated first (Figure 1.1). With further increase in depth, other wavelength components also start to lose significance. The images therefore suffer from limited visibility range, uneven lighting, and presence of bright artifacts. Noise is inevitably apart of any acquired image. Thus a low contrast image with diminished color is obtained.

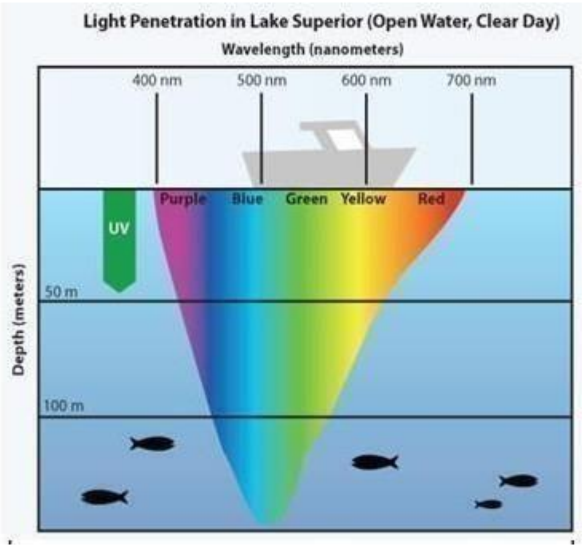


Figure 1.1: Attenuation of components of light with increasing depth underwater

Brief Description of Color Space

As the underwater images portray different attenuations unlike the normal images we use different color spaces to identify them. The approach followed here is to first change the color space of the image acquired. The color spaces used here are 'YCbCr' before applying the enhancement techniques. For example 'LAB' color space is used before applying the CLAHE technique. The reason for choice of color spaces is described ahead. Secondly, histogram equalization is performed along with noise reduction wherever necessary.

The YCbCr color space

One of two primary color spaces used to represent digital component video(the other is RGB). The difference between YCbCr and RGB is that YCbCr represents color as brightness and two color difference signals, while RGB represents color as red, green and blue. In YCbCr, the Y is the brightness (luma), Cb is blue minus luma (B-Y) and Cr is red minus luma (R-Y). As brightness is a separate component in this color space, it is more efficient in contrast enhancement.

The LAB color space

LAB stands for Luminance (or lightness) and A and B (which are chromatic components). According to this model A ranges from green to red, and B ranges from blue to yellow. This model was designed to be device independent. In other words by means of this model you can handle colors regardless of specific devices (such as Monitors, printers, or computers). The Luminance ranges from 0 to 100, the A component ranges from -120 to +120 (from green to red) and the B component ranges from -120 to +120 (from blue to yellow).

Problem Statement

Quality of underwater images is severely affected by the particular physical and chemical characteristics of underwater conditions, raising issues that are more easily overcome in terrestrial imaging. The project aims at improving the quality of the underwater images by applying various image processing algorithms which improve the quality by removing the green-bluish hue, and to adjust the contrast and saturation. The most promising one is the Underwater Color Correction Method (UCM).

Along with that various other algorithms can also be used such as Contrast Limited Adaptive Histogram Equalization (CLAHE), Integrated color model (ICM), Rayleigh Stretching.

Problem Formulation

Underwater images always show color cast, e.g., greenbluish color, which is caused by different attenuation ratios of red, green and blue lights. Also, the particles that are suspended underwater absorb the majority of light energy and change the direction of light before the light reflected from underwater scene reaches the camera, which leads to images having low-contrast, blur and haze

In order to increase the range of underwater imaging, artificial light sources are often used. Yet, artificial light too is affected by absorption and scattering. At the same time, non-uniform illumination is introduced, resulting in bright spots at the center of the underwater image, with insufficient illumination towards the boards.

Feasibility Study

Underwater image color constancy based on DSNMF In 2017, Liu et al. proposed a method called Deep Sparse Non-negative Matrix Factorization (DSNMF) to estimate the illumination of underwater images. First, the observed images were segmented into small blocks, each channel of the local block was reconstructed into a [R, G, B] matrix, and the depth of each input matrix was decomposed into multiple layers by the scarcity constraint of the DSNMF method. The last layer of the factorization matrix is used as the illumination for the patch, and the image is adjusted with sparse constraints. After factorization, the local block illumination of the original image is estimated to obtain the enhanced image [9].

Er. Charanjeet Kaur, Er. Rachna Rajput (May 2015), Ordinary histogram equalization uses the same transformation derived from the image histogram to transform all pixels. This works well when the distribution of pixel values is similar throughout the image. However, when the image contains regions that are significantly lighter or darker than most of the image, the contrast in those regions will not be sufficiently enhanced. The objective is to enhance the underwater images contrast while preserving image brightness [6].

DITHEE DEV K, Mr. S.NATRAJAN (April 2015) . One of the effective methods used to improve the underwater image is the contrast limited adaptive histogram equalization (CLAHE) technique. From the underwater input image calculate the dark channel and is processed under the image segmentation. Then find out whether it contains the influence of artificial light or not. If it is yes remove it using appropriate method and then go for the CLAHE technique. The experimental results of this method significantly improve the visual quality of underwater images by enhancing contrast as well as the noise and artifacts [7].

1.1 Existing System

The existing system requires the parameters of underwater imaging model estimation or use inflexible frameworks which are applicable only for specific scenarios. Like Gray-Edge Assumption (GEA) as color correction methods to modify color and saturation of the images but GEA often fails to enhance the images as the contrast of underwater images is low and the edge features are hazed.

Beer's law is used to regenerate the intensity values of a scene by calculating the absorption of light through water as medium for each of the Red, Green and Blue color channels. The depth of a scene is used as input to this method and assumes all subjects in the scene are at exactly the same depth. This method attempts to compensate for the absorption of each of the wavelengths corresponding to the RGB color channels. The accuracy of this approach depends on the correctness of the calibration parameters in applying Beer's Law to estimate the degree of absorption. The problem with this method is that it assumes that the medium is homogeneous and all parts of the scene are at the same depth. Secondly, calibration is required each time the image is taken because the scene is varying in terms of depth, salinity, water molecules, water type and temperature.

Statistical methods can also be used to correct an image. Using these methods, images are normally corrected based on a priori information. A method using a robot, with a full spectrum of light in a transparent medium has been used for color correction. The light could not be left on continuously due to the high power consumption, therefore from time to time the robot's movement stop and switched on to take still reference images. These reference images are much better in terms of color clarity. These reference images provide training data to a Markov Random Field (MRF) to enhance the image on a pixel by pixel basis. This approach assumes that the neighboring frames are similar. The computational cost is high; it took 40 seconds to correct an image of 400 x 300 pixels on generic pc in 2005. Another similar technique was proposed by which is known as "AQUA".

Due to the low energy of RGB components of underwater images (lacking of illumination in the underwater environments), it is frequent to introduce serious artifacts and halos, amplify the internal noise of the image and even cause color distortion when HE, GWA, WH and their variations are directly used for underwater image enhancement. Since the contrast of underwater images is low and the edge features are hazed, GEA often fails to enhance underwater images[8].

1.2 Advantages and Disadvantages

Advantages

- Image enhancement and restoration methods that tackle typical underwater image impairments, including some extreme degradations and distortions.
- Easy to use, inexpensive, high spatial resolution.
- Useful for low ambient light water images.
- Can be used at night, accurate.
- Remove noises.
- Correct image density and contrast.
- Helps to easily store and retrieve in computers.

Disadvantages

- Due to the low energy of RGB components of underwater images (lacking of illumination in the underwater environments).
- It is frequent to introduce serious artifacts and halos, amplify the internal noise of the image and even cause color distortion when HE, GWA, WH and their variations are directly used for underwater image enhancement.
- Since the contrast of underwater images is low and the edge features are hazed, GEA often fails to enhance underwater images.
- Initial cost is high depending upon the system used.
- Once the system is damaged the image will be lost.

1.3 Proposed System

Underwater images always show color cast, e.g., green bluish color, which is caused by different attenuation ratios of red, green and blue lights and may often fail to exhibit their original hue and saturation. We aim at correcting these to produce better quality images with correct color, hue and saturation.

An Unsupervised Color Correction Method (UCM), which can efficiently remove bluish color cast, increase the low red and low illumination problem in order to achieve high quality images. UCM proposed approach is based on the following three stages[15]:

- Equalization of RGB colors
- Contrast correction of RGB color model
- Contrast correction of HSV color model

1.3.1 Equalization of RGB colors or Color Equalization

To achieve a good quality image requires the equal color values of the RGB components. Unfortunately, in the underwater situation, images are rarely color balanced correctly. In order to equalize the RGB value, the first step of the proposedapproach is to calculate the maximum values. Let IR(i,j), IG(i,j) and I B (i, j) be respectively the red, green and blue components of an RGB image of size M x N pixels, Where i = 1, , M; j = 1, N . The maximum pixel values of each colour component R.nax, Gmax and Bmax are calculated

Rmax = max I R (i,j)

Gmax = max IG(i,j)

Bmax = max IB(i,j)

In the first step, the prominent color cast channel is found using the above equations. Then the average values of each cooler component Ravg, Gavg and Bavg are calculated

$$R_{avg} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} I_R(i,j)$$

$$G_{avg} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} I_G(i,j)$$

$$B_{avg} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} I_B(i,j)$$

The proposed method keeps the dominant color cast channel constant since underwater images always have high blue color as compared to other colors. Therefore high values are used to increase the other colors in order to make the image balanced. Based on dominant color cast, two gain factors are calculated as shown in the following equations. The same equations have also been used to calculate the ratio for face detection

$$A = B_{avg} / R_{avg}$$

$$B = B_{avg} / G_{avg}$$

The highest color channel is set as a target mean and the remamt.ng color channels are determined with a multiplier to match m order to produce a balanced image. The proposed method uses two color channels to reduce the color cast of the affected image. The values are adjusted based on Von Kries hypothesis as given below

R '= A x R

G ' = B x G

Where R and G are original pixels values in the image and R' and G' are the adjusted pixel values.

1.3.2 Contrast correction of RGB color model or global histogramstretching

Low contrast can make an image unclear and difficult to understand or see. Therefore, the second step of the proposed approach IS to apply contrast correction algorithm in order to uproar e the contrast of an image. This is carried out by stretch the range of Intensity values in order to span the desired range of values. Before performing contrast correction, a determination is made for the upper and lower limits of the image for contrast correction of each band. Normally, the range of values in 8-bit color channel is 0-255. Appling the contrast correction method to the inside pixel values as shown in Figure 1.2.

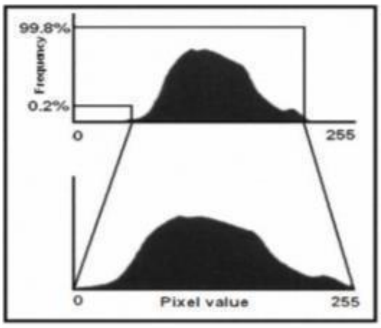


Figure 1.2: Contrast Correction Method

1.3.3 Contrast Correction Method:

In order to apply the contrast correction method, three different steps are used according to the characteristic of the pixels. Contrast correction method is applied to those pixels which are within the range of 0.2% to 99.8%. The following equation is used for contrast correction.

Where,

(b-a) p = (P -c) + a (11) o 1 (d-c)

- Po is the contrast corrected pixel value;
- Pi is the considered pixel value;
- a is the lower limit value which is 0;
- b is the upper limit value which is 255;
- c is the minimum pixel value currently present in the Image;
- d is the maximum pixel value currently present in the Image; In order to achieve better results, it is proposed that the contrast correction. Method should be applied to an image to the upper Side, lower Side and both sides as described below.

1) **Contrast Correction to Upper Side**: Here, the lowest color value component is selected; that is normally the red color component which is the first color that disappears underwater within 3 meters. In this case adjustments are made using contrast correction method. The range of direction is toward maximum side as shown in Figure 1.3.

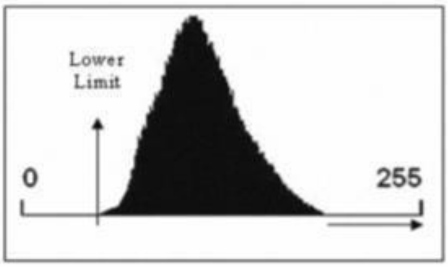


Figure 1.3: Contrast Correction to Upper Side

The contrast correction formula (11) is used but here the emphasis is on (b-a) / (d-c) which is represented as: (Upper Limit - Lower Limit) / (Maximum - Minimum) which is modified as: (Upper Limit - Minimum of Red) / (Maximum - Minimum) Lower Limit = Minimum of Red, Upper limit = 255 Lower limit is set to minimum of Red instead of zero.

2) **Contrast Correction to Lower Side**: In the second step, the prominent color cast component is selected which has heavy color cast and in underwater images that is the blue color. Therefore, underwater images always have a bluish color cast. For the adjustment of blue color cast, the contrast correction method is applied toward minimum side to solve the problem of bluish color cast as shown in Figure 1.4

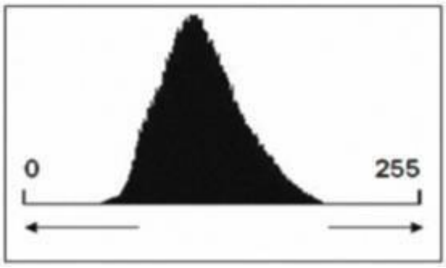


Figure 1.4: Contrast Correction to Lower Side

The contrast correction formula (11) is used but here the emphasis is on (b-a) / (d-c) which is represented as: (Upper Limit - Lower Limit) / (Maximum - Minimum) Which is modified as: (Maximum of Blue - Lower Limit) / (Maximum -Minimum) Lower Limit = 0, Upper Limit = Maximum of Blue Upper limit is set to Maximum of Blue instead of 255.

3) **Contrast Correction to Both Sides:** Here, the proposed approach is applied to find the color component which has the value between lower and higher color components. In this case, adjustments are made toward both directions, minimum and maximum side, using contrast correction method.

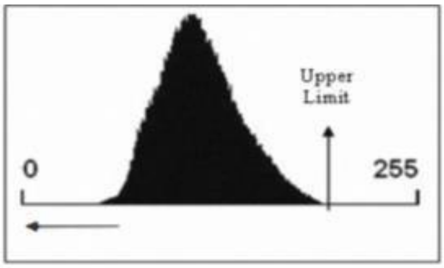


Figure 1.5: Contrast Correction to both sides

The contrast correction formula is used but here the emphasis is on (b-a) / (d-c) which is represented as: (Upper Limit - Lower Limit) / (Maximum - Minimum)
Lower Limit = 0, Upper Limit = 255.

1.3.4 Contrast Correction of HSI Color Model

This section describes how the quality of an image can be improved by applying the HSI color model. Additionally, it describes the conversion of an image from the RGB color model to the HSI color model and vice versa. The HSI color model has three components namely Hue (H), Saturation (S) and Intensity (I). Hue is a pure color component, Saturation is pureness of color and Intensity is an illumination component. Hue channel is a pure color channel. This channel has seven colors, which are the same as the rainbow color. Due to this fact, this channel is kept as a constant in order to avoid the color gamut problem. Unlike hue in the HSI color model that represents several colors, each component in the other color models (such as ROB, CMY and YCrCb) represents only one color [17].

The HSV color model provides a wider color range by controlling the color elementof the image. The Saturation and Intensity are the elements that generate a wider color range. The blue color element in the image can be controlled by the 'S' and 'I' value in order to create the range from pale blue to deep blue. Using this technique, the contrast ratio can be controlled in underwater images by either decreasing or increasing the value. This is carried out by applying a histogram of the digital values for an image and redistributing the stretching value over the image variation of the maximum range of possible values. Furthermore, linear stretching from 'S' value can provide stronger values to each range by looking at the less output values. Using the proposed approach, it is possible to stretch the Saturation and Intensity values of the color model. Importantly, using the Saturation parameters, the true color of the underwater image is obtained.

1.3.5 Advantages of proposed system

- The main reason why UCM method has been able to effectively enhance the image is that it takes into account the image's properties and enhances the image based on its characteristics rather than on static criteria[12].
- The UCM method is designed for underwater images with the assumption that the blue color cast is an integral feature of the images. Therefore this method may not produce good results when applied to images which do not have blue color cast such as land images.
- The UCM method enhances the underwater images better than the existing CLAHE, ICM and Rayleigh Distribution.

1.4 Objectives

- Enhancing the images with using Unsupervised Color Correction Method (UCM).
- Usage of Contrast Limited Adaptive Histogram Image Equalization(CLAHE) Algorithm.
- Implementing underwater image enhancement algorithm based on an Integrated Color Model (ICM) and Rayleigh Stretching.
- Comparing the results produced by these algorithms using Matlab and Edge Detection Algorithms.

1.5 Organization of the Project

Project can be organized in the form of chapters as below:

Chapter 1:this chapter deals with the introduction to the problem under consideration, existing and proposed system and explains the need for enhancing the underwater images.

Chapter 2:this chapter deals with the architecture of the system and module description.

Chapter 3:this chapter deals with the implementation which include UML-diagrams which helps the project to be demonstrated easily.

Chapter 4:this chapter deals with the results of the project and comparison of results.

Chapter 5:this chapter deals with the conclusion and scope for the future means, that is, how the project is used for the future.

2. UNDER WATER IMAGE ENHANCEMENT TECHNIQUES AND IMAGE RESTORATION

2.1 Architecture

The project is developed with python where the UI is done with Flask which isa framework of python. The backend database connection is made with the help of SQLyog community edition.

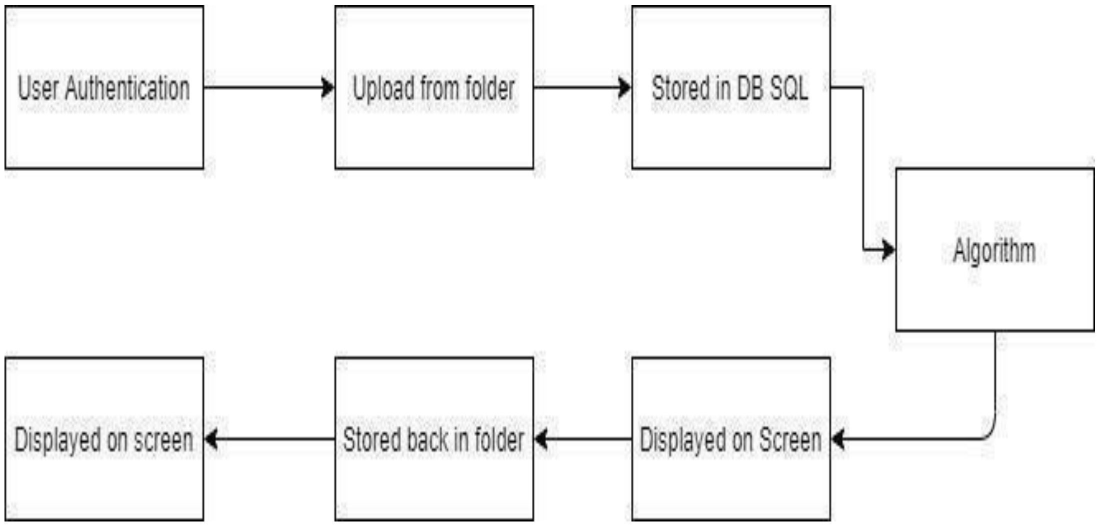


Figure 2.1: Architecture

User authentication verifies the identity of a user attempting to gain access to a network or computing resource by authorizing a human-to-machine transfer of credentials during interactions on a network to confirm a user's authenticity. The user uploads the input image from the folder. The input image given by the user is stored in the database. Applying the Unsupervised Colour Correction (UCM) algorithm for the input image to get the enhanced image. The enhanced image is displayed on the screen and stores back to the folder where the input image is located.

2.2 Module Description

2.2.1 User Interface

User interface is the way through which a user interacts with the website. Firstly, the user has to register and login in to the website to access the home page. In the home page the following buttons are available for different actions as shown in the figure 2.1.

- Upload
- View Image
- View Data

On clicking Upload the user gets navigated to the page where he/she is allowed to upload the image. The image has to be uploaded with proper extension which is Joint Photographic Group (.jpeg). If the image is in other formats it has to be converted into .jpeg. User gives the image as the input.

The user then required to navigate to the View Image page. Where the user can view all the images uploaded till now. He/she can select the required image which needs to be enhanced and click the enhance image button right next to the images displayed. Once enhance image is clicked the enhanced image is displayed on the screen. The underwater image indicates an image with poor visual contrast. Different enhanced images are produced as the output for different algorithms.

The algorithms used are:

- Unsupervised Color Correction
- Contrast Limited Adaptive Histogram Equalization
- Integrated Color Model
- Rayleigh Distribution.

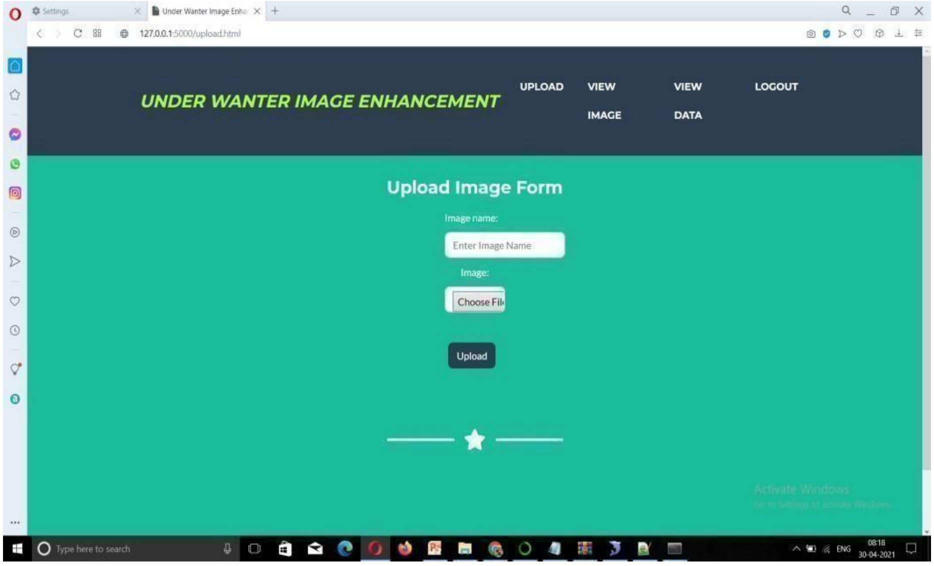


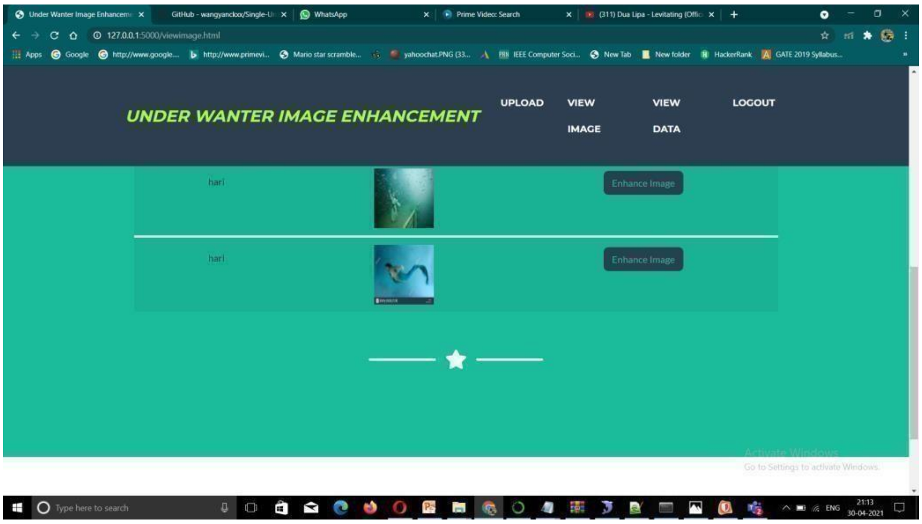
Figure 2.2: User Interface

2.2.2 Image Uploading and Image Enhancement and Restoration

Image enhancement entails operations that improve the appearance to a human viewer, or operations to convert an image to a format better suited to machine processing. These methods do not rely on any physical model of the underwater image formation. Image enhancement aims at making the images more aesthetically pleasing through subjective criteria and without relying on complex mathematical models. Because image restoration requires many model parameters that extremely variable depends on the target's spatial position and water constitution. Consequently, it can be difficult to use in real underwater situations. Therefore, our focus will be laid on dealing with the underwater image enhancement problem and not on image restoration [3].

Image restoration has commonly been defined as the modification of an observed image in order to compensate for defects in the imaging system that produced the observed image. Image restoration aims at estimating the true underwater scene by removing the noise and inverting the degradation process. Doing this usually requires building mathematical models of the degradation and using various signal processing filtering techniques. The figure 2.3 shows the uploading of the image.

Figure 2.3: Image uploading



2.2.3 Display and Compare

The enhanced image is displayed as shown in figure 2.4 and the enhanced image is compared with the input image. The produced enhanced image has better quality image than the input image. The results are promising with the high visual quality images.

For comparison we adopted two techniques. The first one is using MATLAB and the second one is the Canny edge Detection algorithm.

Using MATLAB we can identify the pixels of the image at each and every point. Using the algorithm we can produce images with higher resolution. Image resolution is typically described in PPI, which refers to how many pixels are displayed per inch of an image. Higher resolutions mean that there more pixels per inch (PPI), resulting in more pixel information and creating a high-quality, crisp image. The images produced have colors closer to the original picture without diffusion [16].

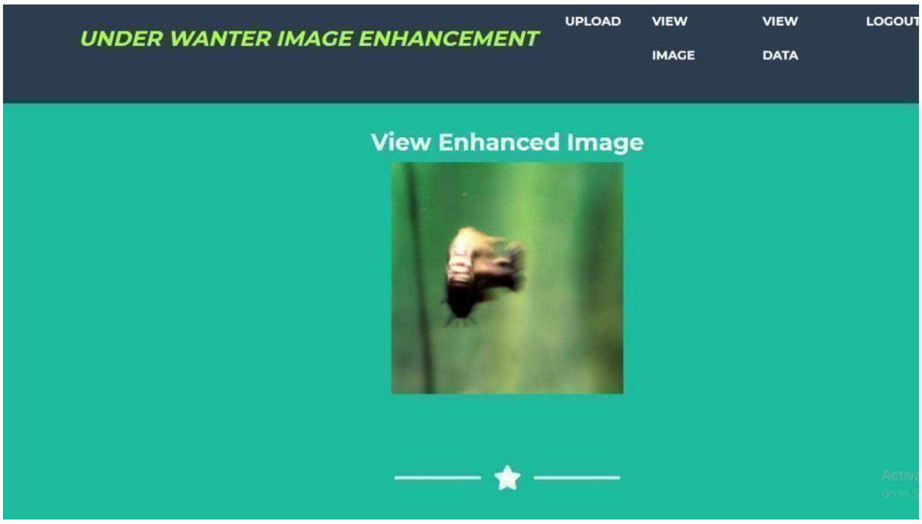


Figure 2.4: Output Display

The total architecture of the project can be as shown in the figure 2.4. The user needs to be authenticated. Once Logged in he can view all the images he previously uploaded under his name. Now he needs to upload an image from a folder. This image is stored in the database and used for the further operations. The algorithm is applied on the image. The output image is stored back to the folder specified and also displayed on the screen.

2.3 Algorithms

2.3.1 Unsupervised Color Correction

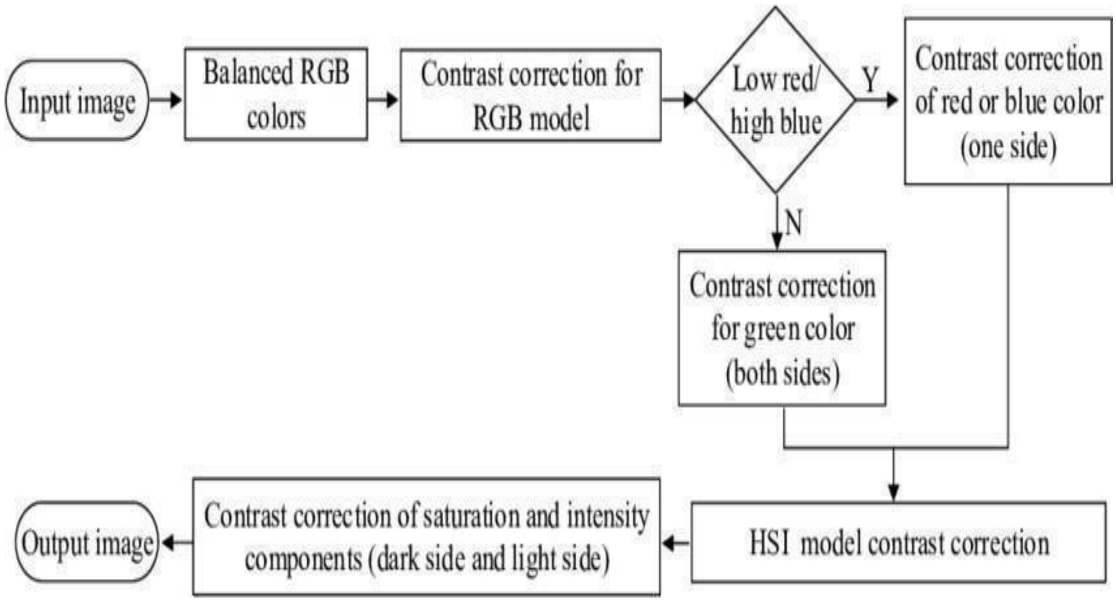


Figure 2.5: UCM algorithm Flowchart

Unsupervised Color Correction Method (UCM) for underwater image enhancement. UCM is based on color balancing, contrast correction of RGB color model and contrast correction of HSI color model. UCM is based on three steps and each step is playing an important role in enhancing underwater images as briefly described below.

Balancing an image

Underwater images always have high blue color as compared to other colors. Therefore this high values are used to increase the other colors in order to make the image balanced.

Removal of color cast

Contrast correction method is playing a vital role in terms of color enhancement because the use of this method can decrease the high blue color cast by stretching the blue histogram towards the minimum side. Similarly, the red color has been increased by stretching the red histogram towards the maximum side. As underwater images are always affected by blue and red colors, the use of two different types of contrast correction methods has helped to adjust high blue and low red color values in order to produce good quality images.

Improvement of illumination and increase of true color

The illumination and true color of underwater images have been increased through Intensity and Saturation parameters of HSI color model. Therefore the images look brighter and richer in colors. The main reason why UCM method has been able to effectively enhance an image is that it takes into account the image's properties and enhances the image based on its characteristics rather than on static criteria.

The UCM method enhances underwater images better than the existing GW, WP and APHE methods. The UCM method is designed for underwater images with the assumption that the blue color cast is an integral feature of these images. Therefore, this method may not produce good results when applied to images which do not have blue color cast such as land images [4].

2.3.2 Contrast Limited Adaptive Histogram Equalization

Histogram equalization (HE) is the most popular underwater enhancement method because of its performance and simplicity. Histogram equalization is a simple method of image enhancement, which improves digital image quality without knowledge about the source of degradation. The operation of HE is to redistribute the probabilities of grey levels occurrences in such a way that the histogram of the output image to be close to the uniform distribution[13].

The image is divided into blocks and the histogram equalization mapping is calculated only for each block and assigned to its central pixel. Then the mapping function for any other pixel is bilinear interpolated from the mapping functions of the pixel’s four surrounding blocks.

A major challenge with the use of traditional AHE is that the method sometimes over amplifies noise in the region having relatively small intensity range. For this, we use Contrast-Limited Adaptive Histogram Equalization (CLAHE) in order to limit the noise amplification. The procedure used by CLAHE algorithm involves partitioning of agiven gray scale image into contextual regions and then equalizes the histogram of each region. The CLAHE applies contrast limiting technique to each neighborhood grid point within a particular region from which a transformation is derived. Noise amplification is reduced by clipping image histogram at a predefined value just before computing the Cumulative Distribution Function (CDF) for each grid point. CLAHE is shown to be superior to the original AHE for its improved noise performance, although it does not completely eliminate noise enhancement in smooth regions, and the selection of contrast gain limit is image-dependent.

2.3.3 Integrated Color Model

Integrated color model (ICM) based on underwater images that slid and stretch in the RGB color space and HSI color space. Firstly, the heavily attenuated GB channels in the RGB color model are stretched through the entire range [0, 255]. Then the image is converted to the HSI color model and the components are finally stretched with sliding histogram stretching to improve the saturation and brightness of the output image. The output image in the red-green-blue (RGB) color model is stretched over the entire dynamic range. The image is then converted to the hue-saturation-intensity (HSI) color model[6].

In this color model, the S and I components are applied with contrast stretching. After stretching, the image in HSI color model is then converted back into the RGB color model to produce an enhanced output image. Contrast correction is then applied in the RGB color model. The image histograms are stretched at one or both sides based on the minimum and maximum values of each channel taken at 0.2% and 99.8% at the minimum and maximum points of the original histogram, respectively. Contrast stretching toward the upper side is applied to red, which is the lowest intensity channel. Contrast stretching at both sides is applied to green, which is the middle intensity value of the color channels, and contrast stretching at the lower side is applied to blue, which is the dominant color cast. For underwater images, the image is further converted into the HSI color model, and the S and I components are stretched at both the lower and upper sides. This technique produces high noise.

The contrast-stretching algorithm is used to enhance the contrast of the image. This is carried out by stretching the range of the color values to make use of all possible values.

The contrast-stretching algorithm uses the linear scaling function to the pixel values. Each pixel is scaled using the following function:

$Po = (Pi - c) \times (b - c) / (d - c) + a$

Where

- Po is the normalized pixel value
- Pi is the considered pixel value
- a is the minimum value of the desired range
- b is the maximum value of the desired range
- c is the lowest pixel value currently present in the image
- d is the highest pixel value currently present in the image .

When the contrast stretching algorithm is applied to color images, each channel is stretched using the same scaling to maintain the correct color ratio.

The first step is to balance the red and green channel to be slightly the same to the blue channel. This is done by stretching the histogram into both sides to get well-spread histogram.

In the second step we transform the RGB image into HSI, using the saturation and intensity transfer function to increase the true color and brightness of underwater images.

2.3.4 Rayleigh Stretching or Rayleigh Distribution

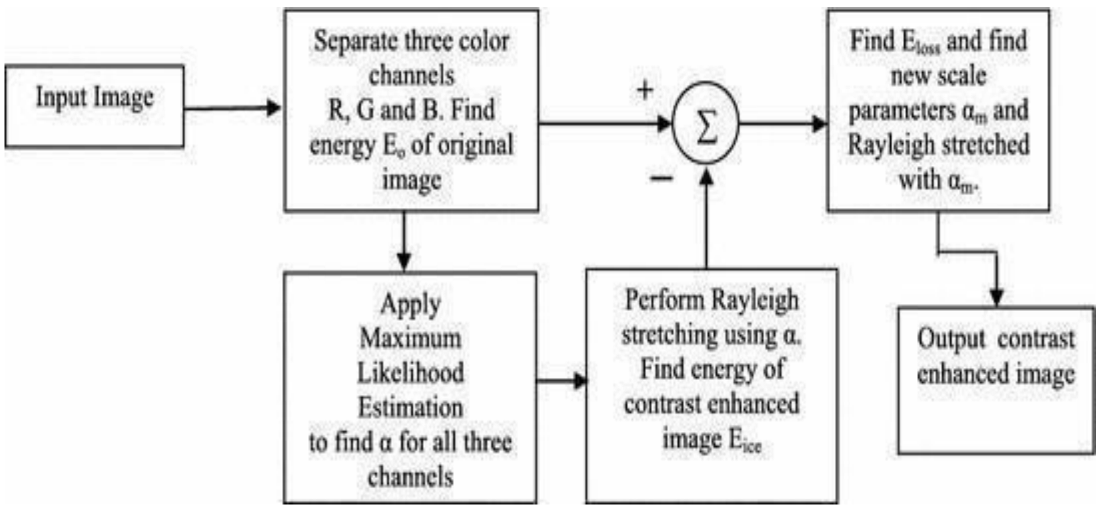


Figure 2.6: Rayleigh stretching flowchart

Rayleigh Stretching extends the ICM by increasing contrast, reducing noise, and increasing the details in underwater image[12].

We are dividing an image from its average pixel value to highest & lowest respectively. Calling it as high contrast & low contrast respectively and Rayleigh stretching of each pixel over its entire range.

Steps:

1. Color channel decomposition

```
b , g , r = cv2.split(img2)
b1, g1, r1 = cv2.split(img1)
```

2. Finding average pixel

First we split down the image in its respective b, g, r channel. We need to find average pixel for each channel.

```
Imdb = ((b2.max()-b2.min())/2)+b2.min()
Imdb = ((g2.max()-g2.min())/2)+g2.min()
Imdb = ((r2.max()-r2.min())/2)+r2.min()
```

3. Rayleigh stretching:

It is based on Rayleigh Distribution algorithm. Here using the basic principle of stretching the pixels over entire range, as mentioned in eq2. Integrating this equation results in dynamic stretching of pixels over the entire range as shown in eq4. Here Rayleigh stretching of 'b' channel for high contrast:

```
b[b<imdb] = imdb
for index,value in np.ndenumerate( b ):
new_value = ((255* (value-imdb))/ ((b2.max()-b2.min())/(alpha**2)))
b[index] = new_value
```

4. Image composition We merges both set of channel to obtain high contrast & low contrast images:

```
res=cv2.merge((b,g,r))
res1=cv2.merge((b1,g1,r1))
```

Apart from these we used Canny Edge detection algorithm which is used to detect the edges in the picture.

2.4 Analysis

2.4.1 Comparison of Images:

The images can be compared based on their pixel at each location using MATLAB. The process can be done with the help of the following commands.
Syntax: info = imfinfo(filename)

It returns a structure whose fields contain information about an image in a graphics file, filename. The info structure contains the following informationfields: Filename, FileModDate, FileSize, Format, FormatVersion, Width, Height, Bit Depth, ColorType, FormatSignature, NumberOfSamples, CodingMethod, CodingProcess, and Comment.

Syntax: impixelinfo (filename)

The Pixel Information tool is a UI panel object, positioned in the lower-left corner of the figure. The tool contains the text label **Pixel info:** followed by the pixel information. Before you move the pointer over the image, the tool contains the default pixel information text (X,Y) Pixel Value. Once you move the pointer over the image, the information displayed varies by image type, as shown in the following table. If you move the pointer off the image, the pixel information tool displays the default pixel information label for that image type. impixelinfo creates a pixel information tool in the current figure. The pixel information tool displays information about the pixel in an image that the cursor is positioned over. The tool displays pixel information for all the images in a figure [5].

2.4.2 Sobel Edge Detector

The Sobel filter is used for edge detection. It works by calculating the gradient of image intensity at each pixel within the image. It finds the direction of the largest increase from light to dark and the rate of change in that direction. The result showshow abruptly or smoothly the image changes at each pixel, and therefore how likely it is that that pixel represents an edge. It also shows how that edge is likely to be oriented. The result of applying the filter to a pixel in a region of constant intensity is a zero vector. The result of applying it to a pixel on an edge is a vector that points across the edge from darker to brighter values.

2.4.3 Canny Edge Detection Algorithm

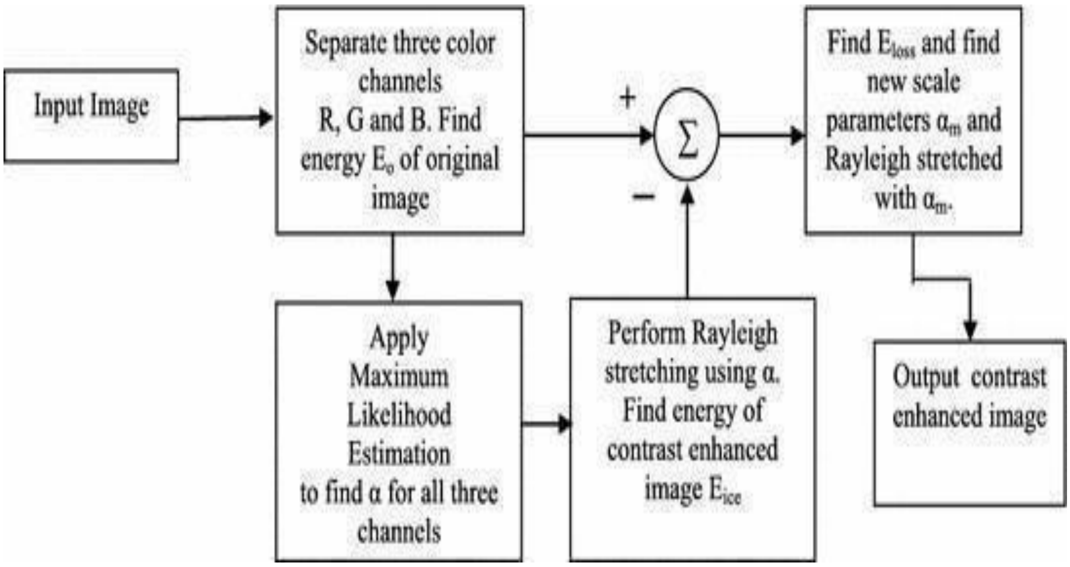


Figure 2.7: Canny edge detection flow chart

The Canny filter is a multi-stage edge detector. It uses a filter based on the derivative of a Gaussian in order to compute the intensity of the gradients. The Gaussian reduces the effect of noise present in the image. Then, potential edges are thinned down to 1-pixel curves by removing non-maximum pixels of the gradient magnitude. Finally, edge pixels are kept or removed using hysteresis threshold on the gradient magnitude [11].

The Canny has three adjustable parameters: the width of the Gaussian (the noisier the image, the greater the width), and the low and high threshold for the hysteresis threshold.

The general criteria for edge detection include:

- Detection of edge with low error rate, which means that the detection should accurately catch as many edges shown in the image as possible
- The edge point detected from the operator should accurately localize on the center of the edge.
- A given edge in the image should only be marked once, and where possible, image noise should not create false edges.

3. IMPLEMENTATION

3.1 Description of Technology Used

Image processing is a method to perform some operations on an image, in order to get an enhanced image or to extract some useful information from it. It is a type of signal processing in which input is an image and output may be image or characteristics/features associated with that image.

Image processing basically includes the following three steps:

- Importing the image via image acquisition tools
- Analyzing and manipulating the image
- Output in which result can be altered image or report that is based on image analysis.

There are two types of methods used for image processing namely, analogue and digital image processing. Analogue image processing can be used for the hard copies like printouts and photographs. Image analysts use various fundamentals of interpretation while using these visual techniques. Digital image processing techniques help in manipulation of the digital images by using computers. The three general phases that all types of data have to undergo while using digital technique are pre-processing, enhancement, and display, information extraction.

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[1].

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.

Types of an image

- BINARY IMAGE– The binary image as its name suggests, contain only two pixel elements i.e. 0 & 1, where 0 refers to black and 1 refers to white. This image is also known as Monochrome.
- BLACK AND WHITE IMAGE– The image which consists of only black and white color is called BLACK AND WHITE IMAGE.
- 8 bit COLOR FORMAT– It is the most famous image format. It has 256 different shades of colors in it and commonly known as Gray scale Image. In this format, 0 stands for Black, and 255 stands for white, and 127 stands for gray.
- 16 bit COLOR FORMAT– It is a color image format. It has 65,536 different colors in it. It is also known as High Color Format. In this format the distribution of color is not as same as Gray scale image.
- A 16 bit format is actually divided into three further formats which are Red, Green and Blue. That well known RGB format.

Image as a Matrix

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

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

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

Phases of Image processing

Acquisition

It could be as simple as being given an image which is in digital form. The main work involves:

a) Scaling

b) Color conversion(RGB to Gray or vice-versa)

Image Enhancement

It is amongst the simplest and most appealing in areas of Image Processing it is also used to extract some hidden details from an image and is subjective.

Image Restoration

It also deals with appealing of an image but it is objective(Restoration is based on mathematical or probabilistic model or image degradation).

Color Image Processing

It deals with pseudo color and full color image processing color models are applicable to digital image processing.

Flask

We take the input from the user through an interface. We connected the model and user interface by using flask.

Flask is a micro web framework written in Python. It is classified as a micro framework because it does not require particular tools or libraries. It has no database abstraction layer, form validation, or any other components where pre-existing third-party libraries provide common functions. However, Flask supports extensions that can add application features as if they were implemented in Flask itself. Extensions exist for object-relational mappers, form validation, and upload handling, various open authentication technologies and several common framework related tools.

3.2 UML Diagrams

The Unified Modeling Language allows the software engineer to express an analysis model using the modeling notation that is governed by a set of syntactic semantic and pragmatic rules.

A UML system is represented using five different views that describe the system from a distinctly different perspective.

3.2.1 Use Case Diagram

A use case diagram is a behavior diagram in UML. Use case diagrams model the functionality of a system using actors and use cases. Use cases are a set of actions, services, and functions that the system needs to perform. The "actors" are people or entities operating under defined roles within the system. In the below use case diagram Users are actors, UCM. Ovals with verbs that represent the system's functions like register, login, upload image, apply UCM algorithm, view image on web page and logout.

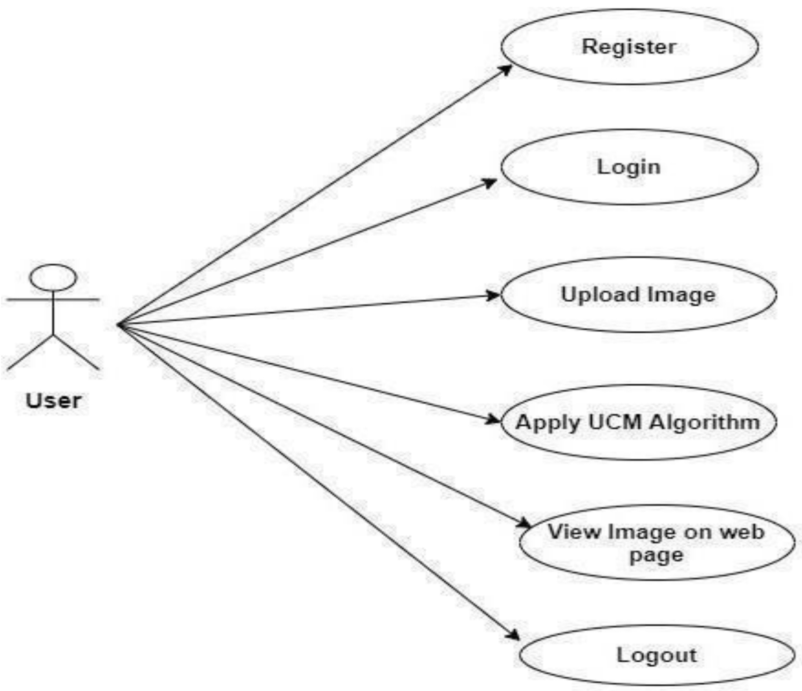


Figure 3.1: Use Case Diagram

3.2.2 Sequence Diagram

The sequence diagram presented in below fig 3.2 depicts the sequential order of the actions of the application underwater image enhancement and image restoration. The actors are user, user interface of underwater image enhancement and backend system. User enter the credentials and register to the portal, if user already got registered he/she can login to portal and upload the image of their choice and then enhance the upload image by using UCM algorithm and view enhanced image as a result on web page.

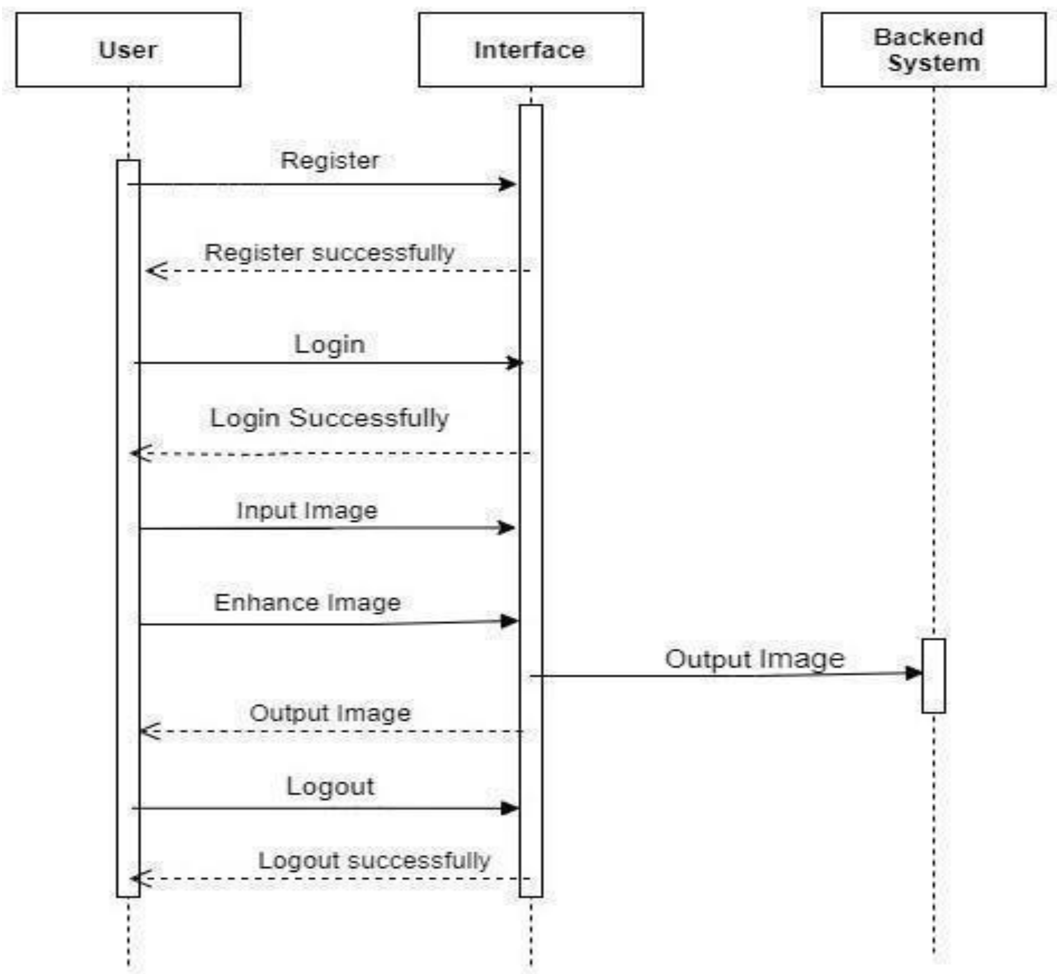


Figure 3.2: Sequence Diagram

3.2.3 Activity Diagram

The action states of activity diagram for underwater image enhancement are enter user interface, register into portal, upload image, apply UCM algorithm, get result and show the result on web page.

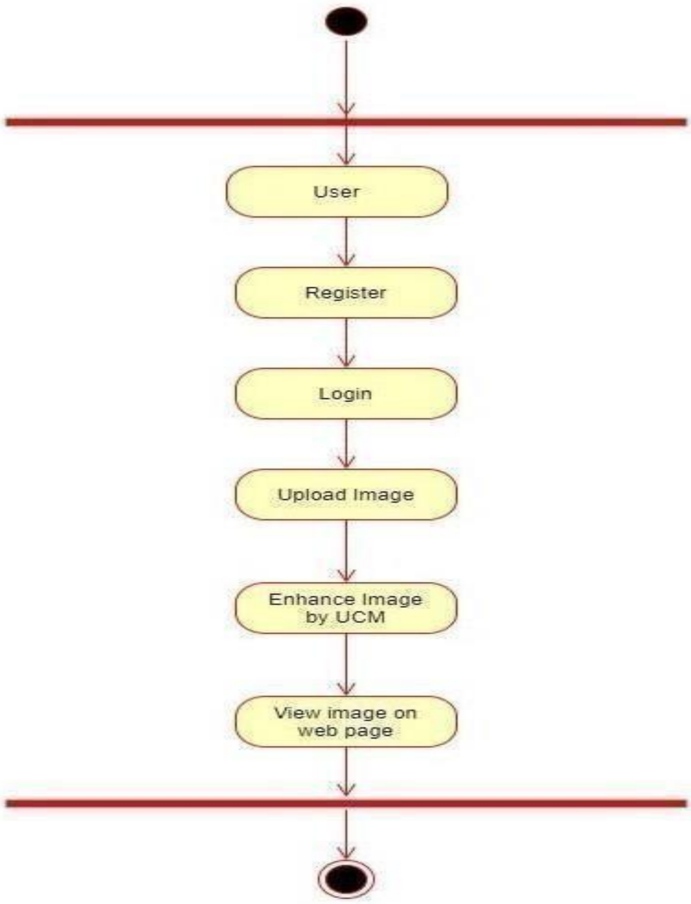


Figure 3.3: Activity Diagram

4. RESULTS AND DISCUSSIONS

4.1 Discussion on Results

The UI provided enhances the images using UCM as it is proved to be producing better results than any other image enhancement algorithms. The results produced are run on MATLAB to find the pixel and file information. The results produced are also given as input to Canny edge detection algorithm to get the edges[2].

The following show the images generated by various image enhancement Algorithms. The figure 4.1(a) is the original image of the sea diver. It has blue color dominated as the sea water absorbs colors in the red part of the light spectrum. Like a filter, this leaves behind colors in the **blue** part of the light spectrum for us to see.The **ocean** may also take on green, red, or other hues as light bounces off of floating sediments and particles in the water. The figures 4.1(b) to 4.1(e) depict the outputs of CLAHE, ICM, Rayleigh distribution and UCM respectively. Out of which UCM produces the best results than any other algorithm. By removing the bluish background we can get the original quality of images. But the hue of the image is preserved while the saturation and brightness are adjusted.

Sea Diver with Oxygen Tank

Figure 4.1 (a) Original

Fig 4.1(b) CLAHE

Figure 4.1(c) ICM

Figure 4.1(d) Rayleigh Distribution

Figure 4.1(e) UCM

Aquarium sea plant and fishes

Figure 4.2(a) Original

Figure 4.2(b) CLAHE

Figure 4.2(d) Rayleigh Distribution

Figure 4.2(c) ICM

Figure 4.2(e) UCM

A School of fishes

Figure 4.3(a) Original

Figure 4.3(b) CLAHE

Figure 4.3(d) Rayleigh Distribution

Figure 4.3(c) ICM

Figure 4.3(e) UCM

4.2 Comparison of results

The accuracy of the image can assessed only if the original image without water is available so that the results produced can be compared to the original output. But it is not possible to obtain an image like that without water in the foreground. So other techniques like pixel information, file size, time of execution of the algorithm and edge detection on the results produced are compared on the outputs of all the algorithms to find out which produces the best results.

4.2.1 File size

Larger images or higher resolution images generally have larger file sizes. However, two images of the same size or resolution are not always the same file size. The number of colors and the variation of those colors impacts file size[16]. The images below in figures 4.4 depict the same.

```
>> imfinfo('1.Original.jpg')

ans =

  struct with fields:

           Filename: 'C:\Users\NIKHIL\Desktop\Sujitha_Project_Images\1.Original.jpg'
        FileModDate: '23-May-2021 18:38:05'
           FileSize: 4750
             Format: 'jpg'
      FormatVersion: ''
              Width: 194
             Height: 259
           BitDepth: 24
          ColorType: 'truecolor'
    FormatSignature: ''
    NumberOfSamples: 3
       CodingMethod: 'Huffman'
      CodingProcess: 'Sequential'
            Comment: {}
```

Figure 4.4 (a) Sea diver Original (b) File size information

```
>> imfinfo('ICM.jpg')

ans =

  struct with fields:

           Filename: 'C:\Users\NIKHIL\Desktop\Sujitha_Project_Images\ICM.jpg'
        FileModDate: '23-May-2021 18:38:10'
           FileSize: 14290
             Format: 'jpg'
      FormatVersion: ''
              Width: 194
             Height: 259
           BitDepth: 24
          ColorType: 'truecolor'
    FormatSignature: ''
    NumberOfSamples: 3
       CodingMethod: 'Huffman'
      CodingProcess: 'Sequential'
            Comment: {}
```

Figure 4.4 (a) Sea diver ICM (b) File size information

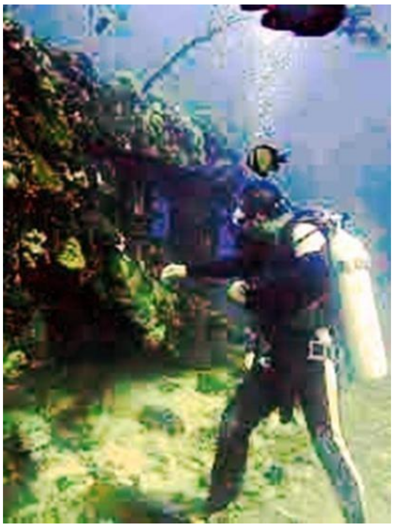
```
>> imfinfo('CLAHE.jpg')

ans =

  struct with fields:

           Filename: 'C:\Users\NIKHIL\Desktop\Sujitha_Project_Images\CLAHE.jpg'
        FileModDate: '23-May-2021 18:38:14'
           FileSize: 16057
             Format: 'jpg'
      FormatVersion: ''
              Width: 194
             Height: 259
           BitDepth: 24
          ColorType: 'truecolor'
    FormatSignature: ''
    NumberOfSamples: 3
       CodingMethod: 'Huffman'
      CodingProcess: 'Sequential'
            Comment: {}
```

Figure 4.4 (a) Sea Diver CLAHE (b) File size information



```
>> imfinfo('RayleighDistribution.jpg')

ans =

  struct with fields:

           Filename: 'C:\Users\NIKHIL\Desktop\Sujitha_Project_Images\RayleighDistribution.jpg'
        FileModDate: '23-May-2021 18:38:13'
           FileSize: 25946
             Format: 'jpg'
      FormatVersion: ''
              Width: 194
             Height: 259
           BitDepth: 24
          ColorType: 'truecolor'
    FormatSignature: ''
    NumberOfSamples: 3
       CodingMethod: 'Huffman'
      CodingProcess: 'Sequential'
            Comment: {}
```

Figure 4.4 (a) SeaDiver RD (b) File size information

```
>> imfinfo('UCM.jpg')

ans =

  struct with fields:

           Filename: 'C:\Users\NIKHIL\Desktop\Sujitha_Project_Images\UCM.jpg'
        FileModDate: '23-May-2021 18:38:07'
           FileSize: 18866
             Format: 'jpg'
      FormatVersion: ''
              Width: 194
             Height: 259
           BitDepth: 24
          ColorType: 'truecolor'
    FormatSignature: ''
    NumberOfSamples: 3
       CodingMethod: 'Huffman'
      CodingProcess: 'Sequential'
            Comment: {}
```

Figure 4.4 (a) SeaDiver RD (b) File size information

4.2.2 Edge Detection

Several researchers have used edge detection method in order to evaluate the performances of their methods based on number of edges found in the image. Edge detection is an image processing technique for finding the boundaries of objects within images. It works by detecting discontinuities in brightness. Edge detection is used for image segmentation and data extraction in areas such as image processing, computer vision, and machine vision. As our major goal here is to improve contrast between the background and foreground images the more the edger implies the better the image quality [17].

Edge detection includes a variety of mathematical methods that aim at identifying points in a digital image at which the image brightness changes sharply or, more formally, has discontinuities. The points at which image brightness changes sharply are typically organized into a set of curved line segments termed edges.

Underwater images raise new challenges in the field of digital image processing technology in recent years because of its widespread applications. There are many tangled matters to be considered in processing of images collected from water medium due to the adverse effects imposed by the environment itself. Image segmentation is preferred as basal stage of many digital image processing techniques which distinguish multiple segments in an image and reveal the hidden crucial information required for a peculiar application. There are so many general purpose algorithms and techniques that have been developed for image segmentation. Discontinuity based segmentation are most promising approach for image segmentation, in which Canny Edge detection based segmentation is more preferred for its high level of noise immunity and ability to tackle underwater environment.

The figure 4.5 depicts the edge detection on various algorithm outputs. The first one is the original image and the left to it is the edges detected by canny edge detection algorithm

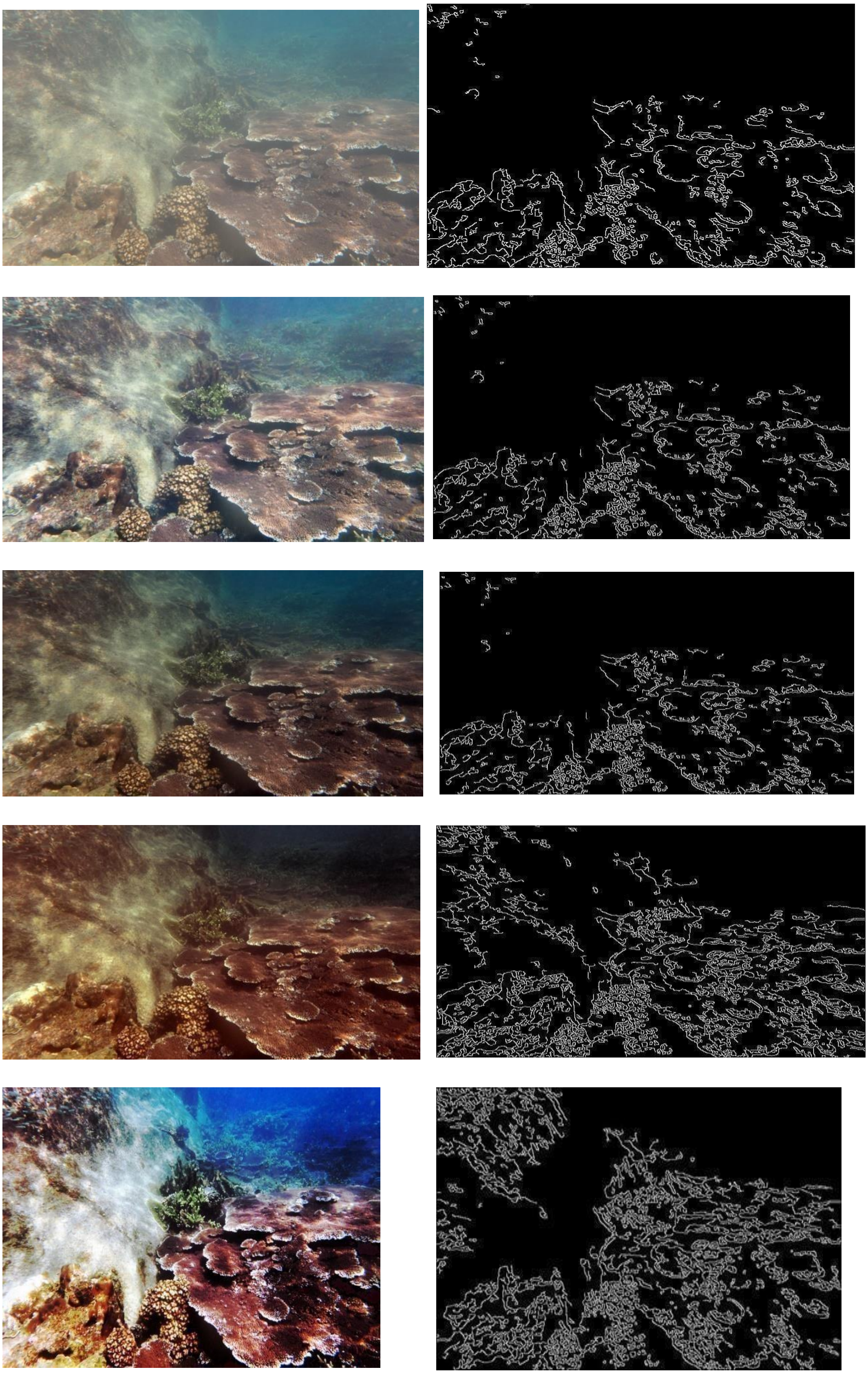


Figure 4.5 Canny edge Detection (Top to bottom) Original image, ICM enhanced, CLAHE enhanced, Rayleigh enhanced, UCM enhanced. (Left to right) RGB picture, edge detection.

Another tool called the Automatic Sobel edge detector can be used for edge detection and edge counting. Figures 4.6 depict edges and number of edges.

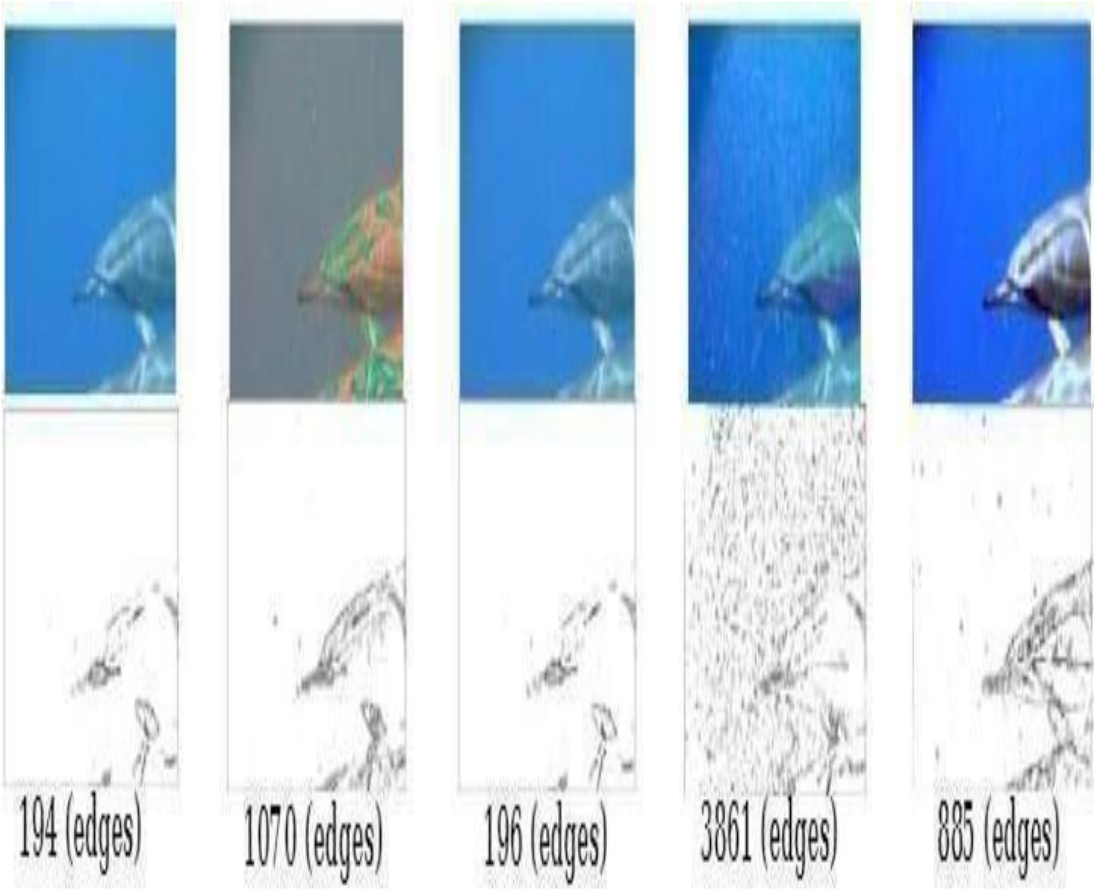


Figure 4.6 Sobel Edge Detection (Left to right row1) Original image, ICM enhanced, CLAHE enhanced, Rayleigh enhanced, UCM enhanced. (Left to right row2) RGB picture, edge detection.

4.2.3 Histogram of RGB

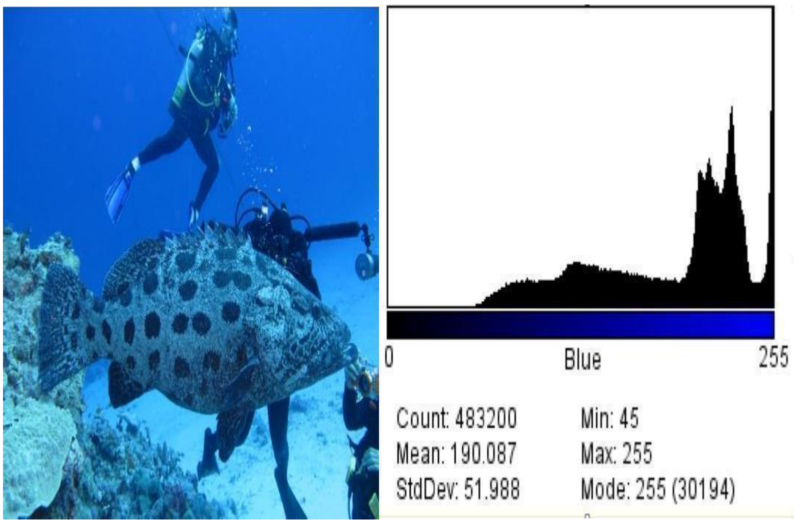
The histogram is a graph on your LCD showing the distribution of each primary color's brightness level in the image (RGB or red, green, and blue). The horizontal axis indicates the color's brightness level (darker on the left and brighter on the right), while the vertical axis indicates how many pixels exist for each color brightness level

The more pixels on the left, the darker and less prominent the color. And the more pixels there are toward the right, the brighter and denser the color. If there are too many pixels on the left, the color info will be lacking. If there's too many on the right, the color will be too saturated.

A **color histogram** is a representation of the distribution of colors in an image. For digital images, a color histogram represents the number of pixels that have colors in each of a fixed list of color ranges, that span the image's color space, the set of all possible colors.

The wider histogram represents a more visually appealing image. In order to achieve that, the histogram should be stretched to the minimum (0) and maximum (255) value level. It can be noted in the Figure 4.10 that the histograms generated by UCM images are stretched well to both minimum (0) and maximum (255) sides. Whereas the histograms generated by the original image are not are not fully stretched.

Where a histogram is a bar graph, whose X-axis represents the tonal scale(black at the left and white at the right), and Y-axis represents the number of pixels in an image in a certain area of the tonal scale.



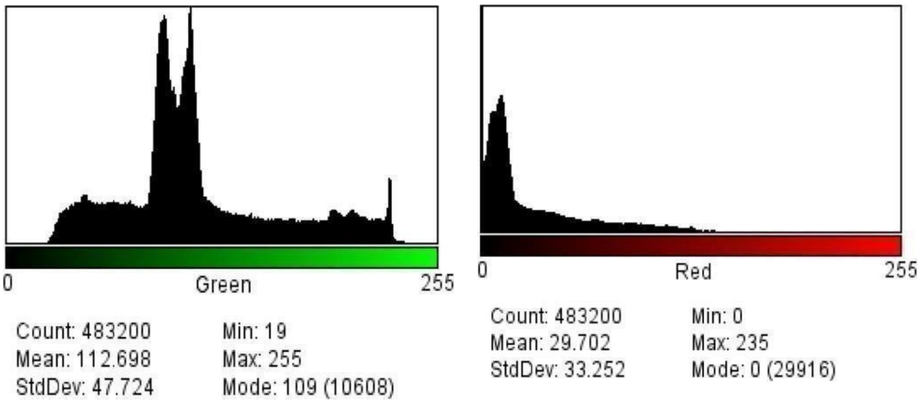


Figure 4.7 Original Image and Histogramof Blue, Red, Greencolors

ImageJ software is used to produce the histograms for the images.

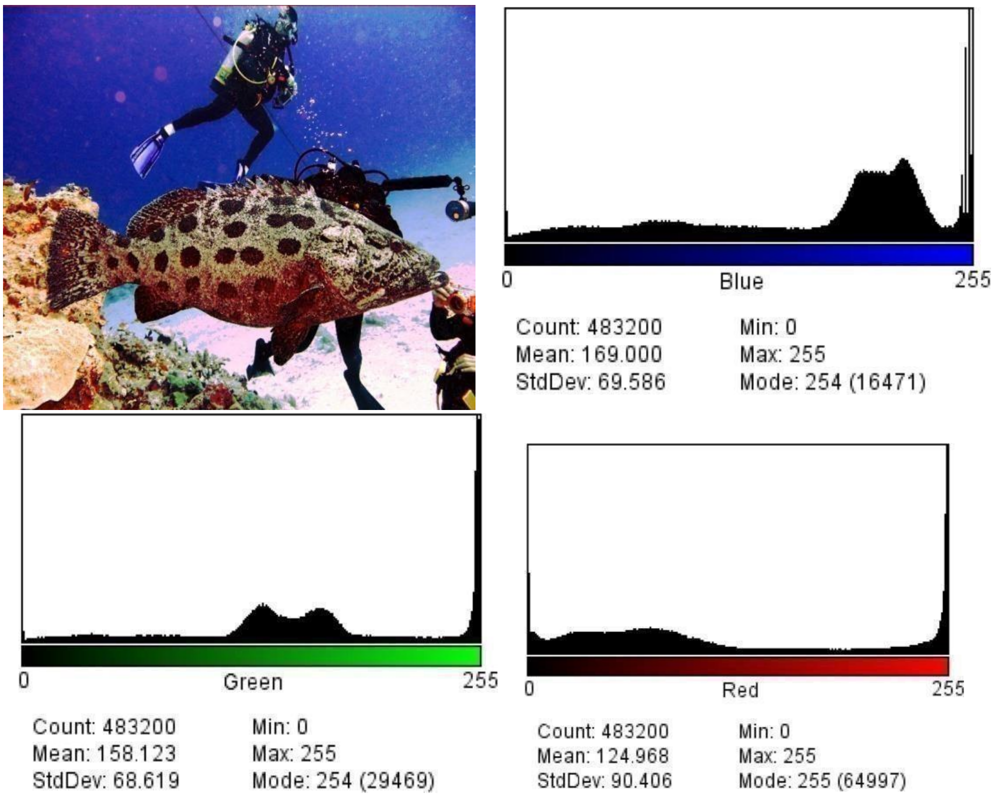


Figure 4.8 Rayleigh Distribution enhanced Image and Histogram of Blue, Red, Green colors

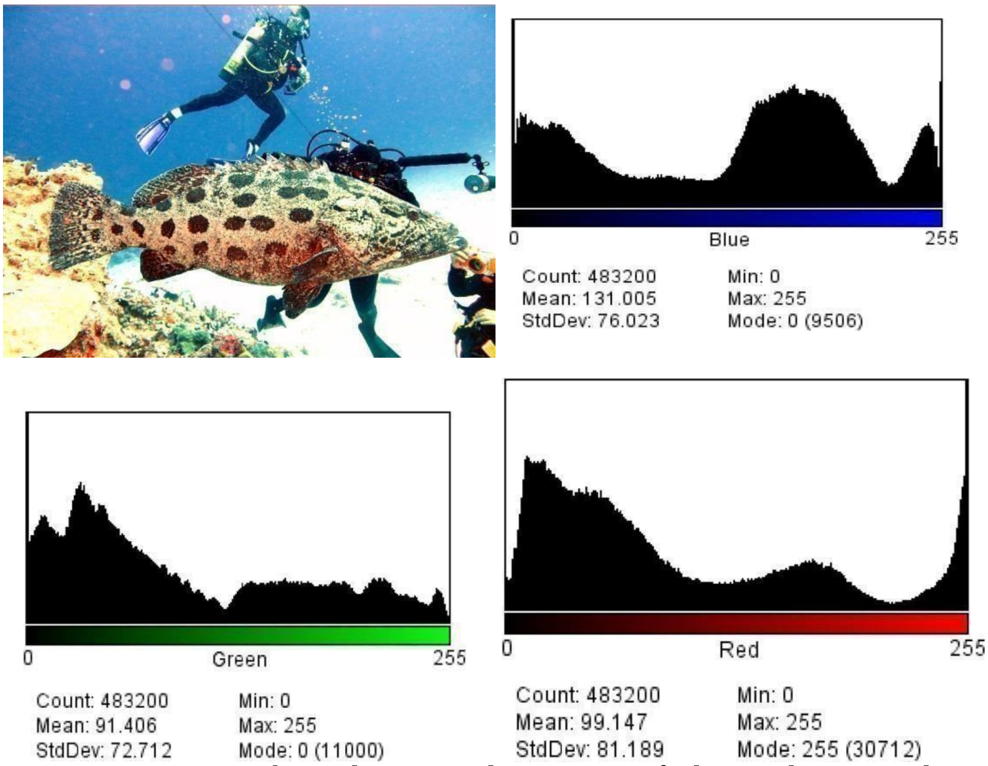


Figure 4.9 UCM enhanced Image and Histogram of Blue, Red, Green colors

4.2.4 Time of running

For a total of 10 images UCM takes a time of 0:05:05.284082 minutes Rayleigh Distribution takes 0:07:05.293902 minutes ICM takes 0:06:45.837450 minutes. CLAHE takes 0:08:58.893010 minutes. The images in figure 5.10 have been used to check the running times of the algorithms.

Figure 4.10 these are 10 raw images for checking time

Algorithm	File Size (in pixels) (for Figure 5.4)	Edges Detected (for Figure 5.7)	Red (min)	Red (max)	Blue (min)	Blue (max)	Green (min)	Green (max)	Time to process 10 raw pictures
Original Image	4750	943	0	235	45	245	19	235	------------------
UCM	18866	3600	0	255	0	255	0	255	0:05:05.284082
Rayleigh Distribution	25946	1070	0	255	0	255	0	255	0:07:05.293902
ICM	14290	1135	0	245	35	245	10	235	0:06:45.837450
CLAHE	16057	945	0	145	35	245	12	142	0:08:58.893010

Table 4.1 Comparison of various parameters of the outputs produced by various images.

The above table 4.1 provides an all-round comparison of various parameters like file size, number of edges detected, minimum and maximum intensity values of red, blue and green pixels and time consumed for processing 10 raw images.

4.3 Screenshots

For the ease of usage we have designed a user interface to upload the images from the folder and to view them on the screen.

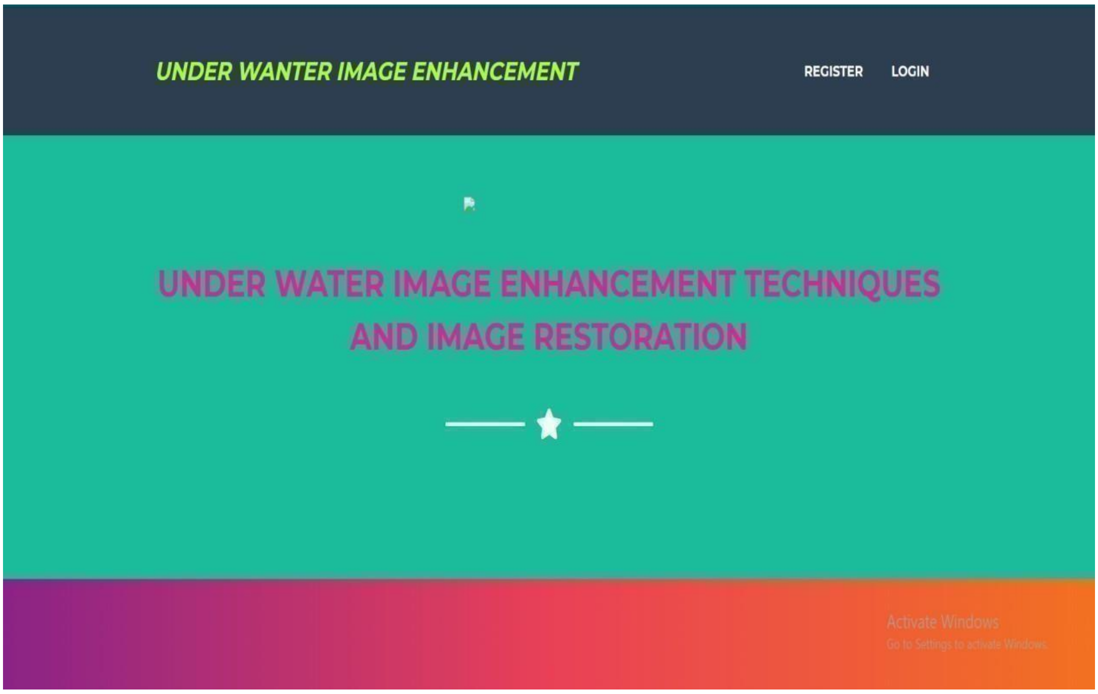


Figure 4.11(a) Index Page

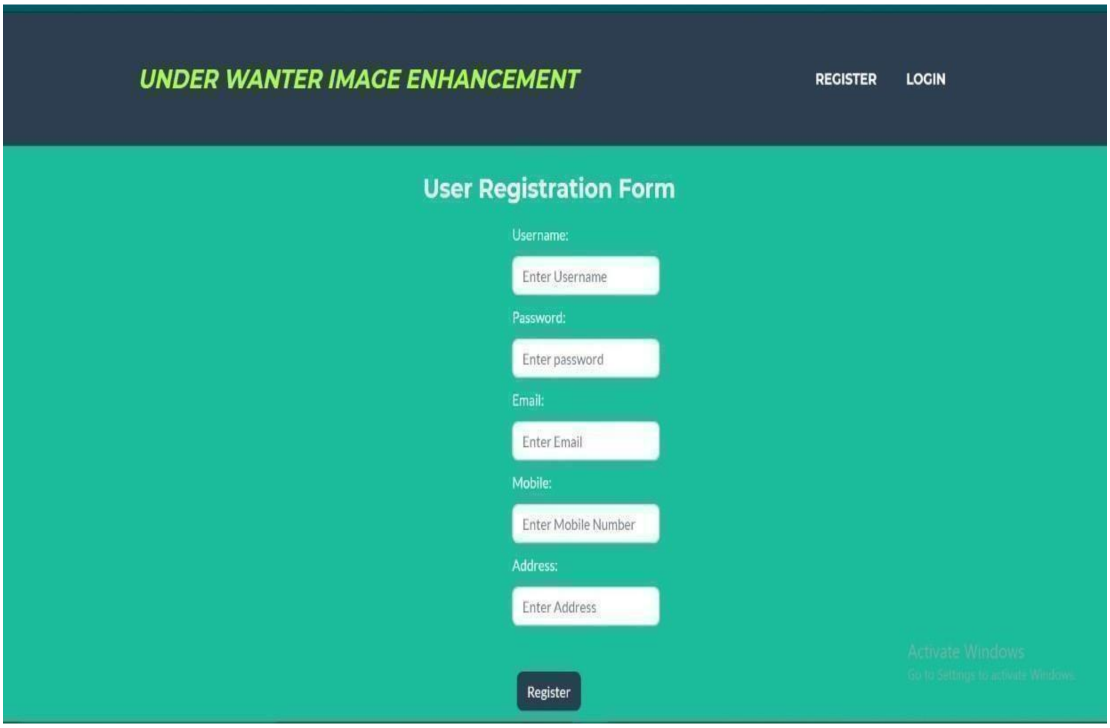


Figure 4.11(b) Registration Page

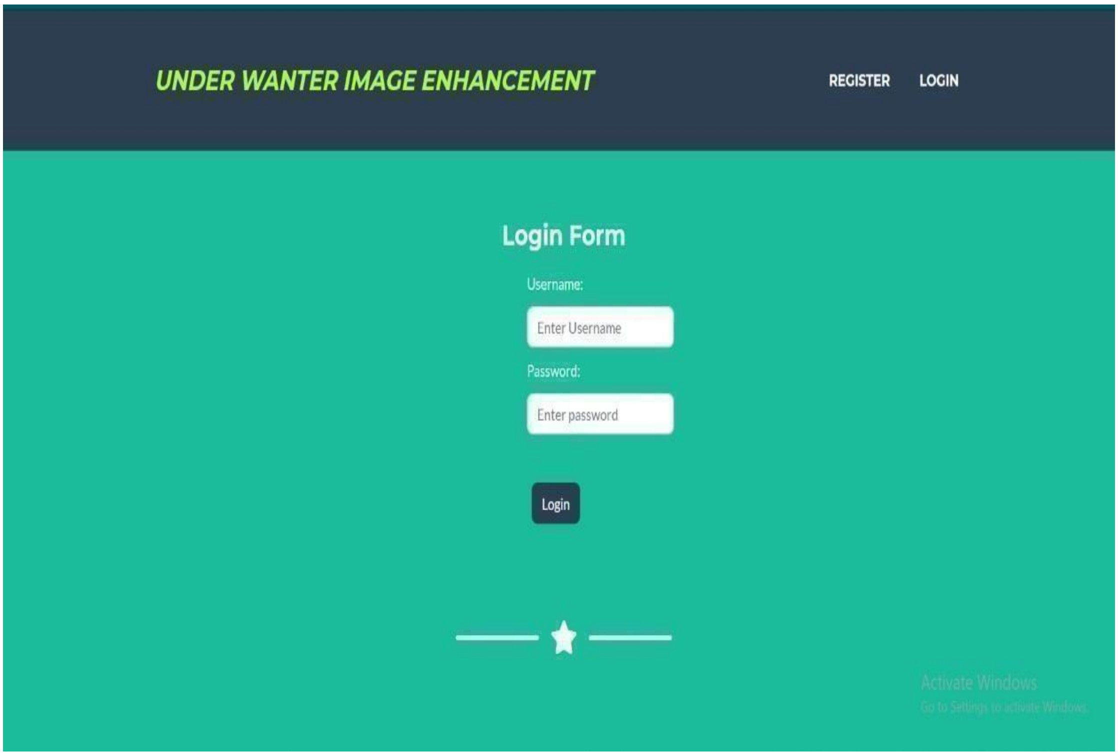


Figure 4.11(c) Login Page

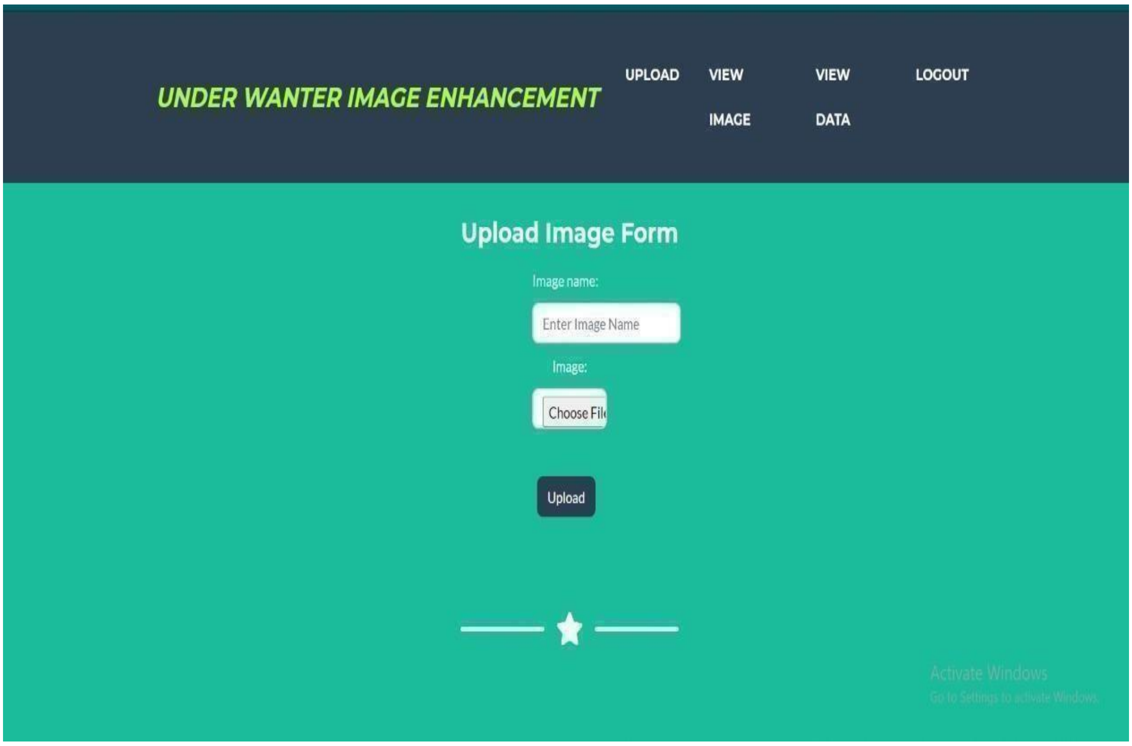


Figure 4.11(d) Upload image

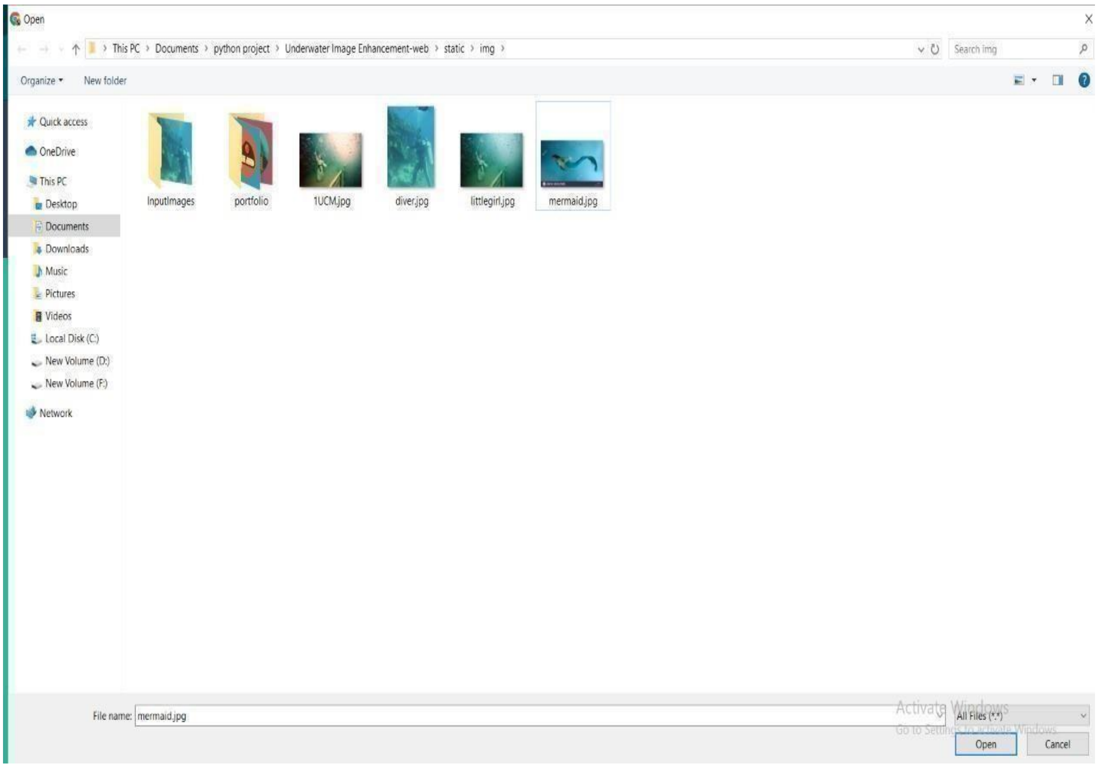


Figure 4.11(e) The Picture should be downloaded in the desired folder prior to uploading

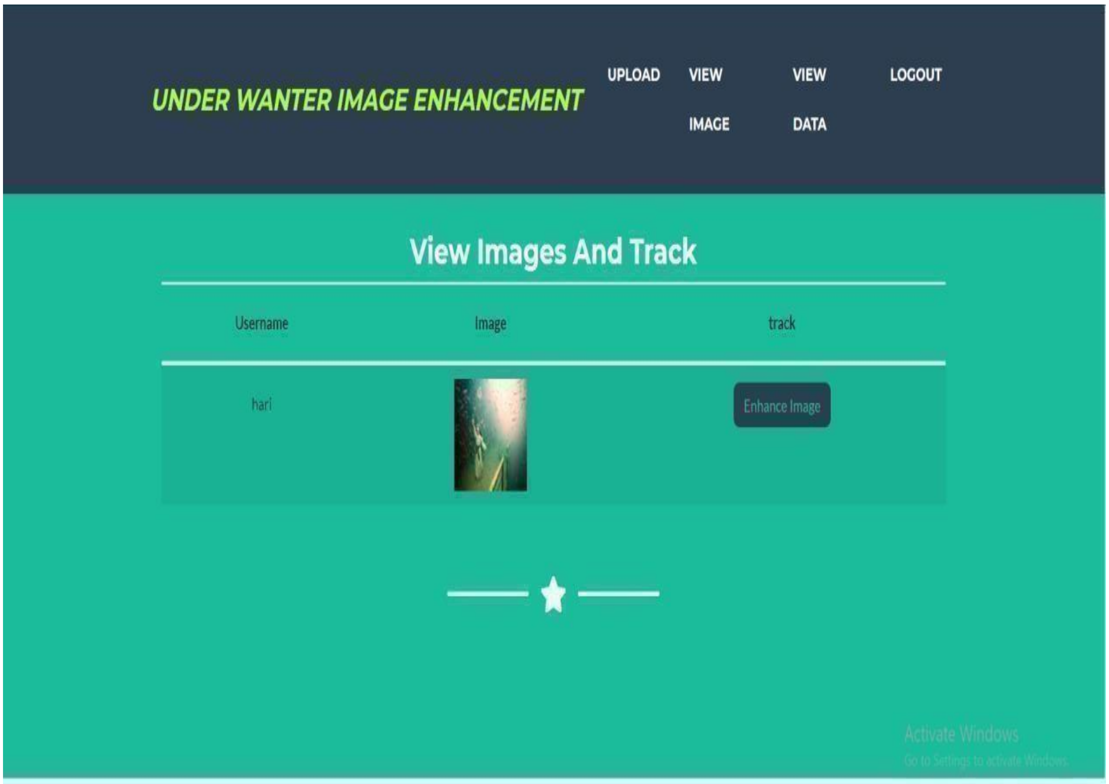


Figure 4.11(f) View the data uploaded

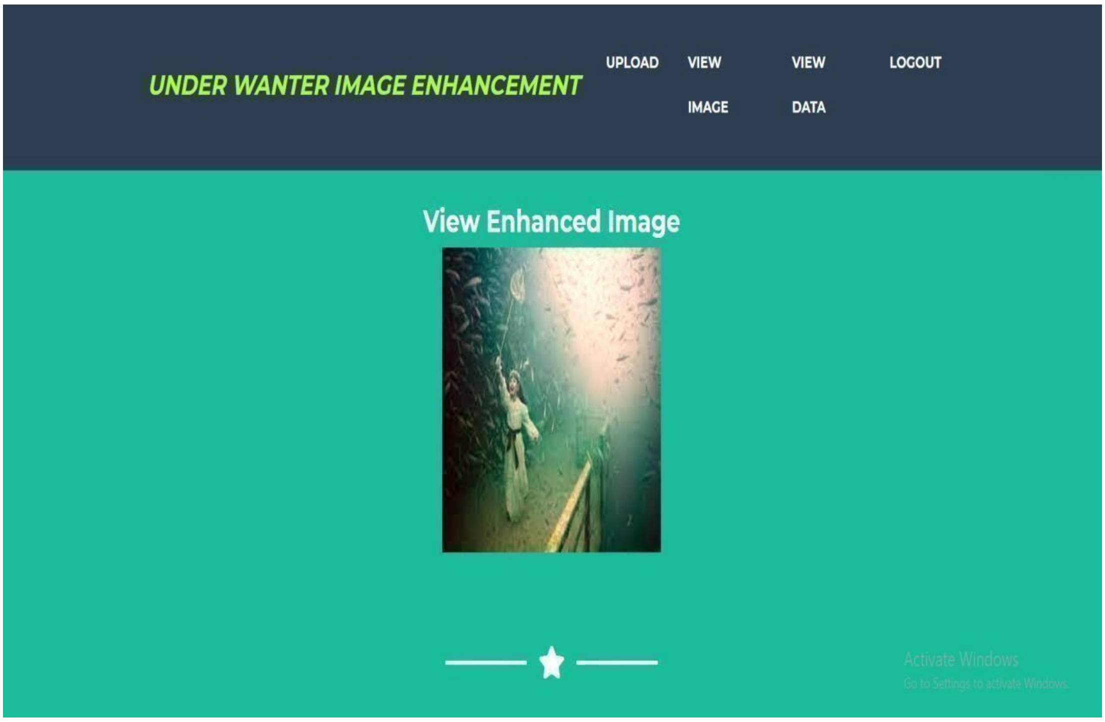


Figure 4.11(g) Results

5. CONCLUSION AND FUTURE ENHANCEMENT

Conclusion

Underwater images are affected by high bluish color cast, low red color and low illumination problem due to absorption, turbidity and scattering of light in aquatic environment. This project used an Unsupervised Color Correction Method (UCM) approach for underwater image enhancement. The approach is based on contrast correction of RGB and HSI color model and efficiently removes the bluish color cast and improves the low red color; as well as improves the low illumination and true colors of underwater images are enhanced. In order to evaluate the performance of the proposed method, the results are compared with the three existing methods, Contrast Limited Adaptive Histogram Equalization (CLAHE), Integrated color Model (ICM) and Rayleigh Distribution. The evaluation is based on file size comparison, edge detection, histogram analysis and runtime. It has been shown that the proposed method has obtained the best results compared to the existing methods.

Future Enhancement

Although single underwater image enhancement and restoration methods have made tremendous progress, still today there is no algorithm that can be effectively applied to enhance underwater images captured from diverse environments, depths or scenes. The adaptability and robustness of underwater image enhancement methods still need to be improved. The future works should focus on the follow aspects like improving the robustness and computational efficiency of underwater image enhancement methods. The desired image enhancement method should be able to adapt to various underwater conditions and develop an applicable enhancement strategy for different kinds of underwater applications.

Constructing a sufficient underwater image benchmark dataset. Until now, there is still a lack of publicly available underwater image datasets, including pairs of hazed and clear underwater images, underwater image background lights, and depth maps. Hence, it is important to construct a public underwater image benchmark dataset with various pairs of hazed and enhanced images. Establishing an effective underwater image quality assessment metric. Current underwater image enhancement methods focus on improving the perceptual effect of images but ignore whether the enhanced images can increase the accuracy of high-level feature analysis such as target detection and classification. Studying deep-sea image enhancement methods. A new imaging model for deep-sea imaging environment is needed to solve light attenuation, uneven illumination, scattering interference and low brightness of deep-sea images, so as to improve the sense of reality of images and reduce the halo effect.

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GLOSSARY

1) **Attenuation:** attenuation describes the density or darkness ofthe image.
2) **Calibration:** Image calibration provides a pixel-to-real-distance conversion factor (i.e. the calibration factor, pixels/cm), that allows image scaling to metric units. This information can be then used throughout the analysis to convert pixel measurements performed on the image to their corresponding values in the real world.
3) **Contrast:** Contrast is the difference in luminance or color that makes an object (or its representation in an image or display) distinguishable. In visual perception of the real world, contrast is determined by the difference in the color and brightness of the object and other objects within the same field of view.
4) **Hue:** Hues are made up of the three primary colors (red, blue, and yellow) and the three secondary colors (orange, green, and violet) that appear in the color wheel or color circle.
5) **Image Resolution**: Resolution refers to the number of pixels in an image. Resolution is sometimes identified by the width and height of the image as well as the total number of pixels in the image. For example, an image that is 2048 pixels wide and 1536 pixels high (2048 x 1536) contains (multiply) 3,145,728 pixels (or 3.1 Megapixels).
6) **Image Restoration:** Image restoration is the operation of taking a corrupt/noisy image and estimating the clean, original image.
7) **ImageJ Software:** ImageJ is a public domain Java image processing program. It runs, either as an online applet or as a downloadable application, on any computer with a Java 1.1 or later virtual machine. ImageJ can display, edit, analyze, process, save and print 8-bit, 16-bit and 32-bit images.
8) **Intensity:** intensity image as a single matrix, with each element of the matrix corresponding to one image pixel.
9) **Luminance:** Luminance is a photometric measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that passes through, is emitted from, or is reflected from a particular area, and falls within a given solid angle.
10) **Matrix Factorization:** Matrix factorization is a class of collaborative filtering algorithms used in recommender systems. Matrix factorization algorithms work by decomposing the user-item interaction matrix into the product of two lower dimensionality rectangular matrices.
11) **Pixel:** In digital imaging, a pixel (or picture element) is the smallest item of information in an image. Pixels are arranged in a 2-dimensional grid, represented using squares. Each pixel is a sample of an original image, where more samples typically provide more-accurate representations ofthe original.
12) **Pixels per inch (PPI):** Pixels per inch (PPI) is the measure of resolution in a digital image or video display. A pixel is an area of illumination or color on a screen or computer image. PPI measures the display resolution, or pixel density, of a computer monitor or screen.
13) **RGB Histogram:** The histogram is a graph on your LCD showing the distribution of each primary color's brightness level in the image (RGB or red, green, and blue).

14) **Saturation:** Color saturation is the intensity and purity of a color as displayed in an image. The higher the saturation of a color, the more vivid and intense it is. The lower a color's saturation, the closer it is to pure grayon the grayscale.
15) **Segmentation:** Image segmentation is the process of partitioning a digital image into multiple segments (sets of pixels, also known as image objects). Image segmentation is typically used to locate objects and boundaries (lines, curves, etc.) in images.
16) **Sobel edge detector:** Sobel filter is used in image processing and computer vision, particularly within edge detection algorithms where it creates an image emphasizing edges.
17) **Vingetting:** In photography and optics, vignetting is a reduction of an image's brightness or saturation toward the periphery compared to the image center.