Enhancing The Low Quality Images Using Unsupervised Colour Correction Method

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***Abstract*— Underwater images are affected by reduced contrast and non-uniform colour cast due to the absorption and scattering of light in the aquatic environment. This affects the quality and reliability of image processing and therefore colour correction is a necessary pre-processing stage. In this paper, we propose an Unsupervised Colour Correction Method (UCM) for underwater image enhancement. UCM is based on colour balancing, contrast correction of RGB colour model and contrast correction of HSI colour model. Firstly, the colour cast is reduced by equalizing the colour values. Secondly, an enhancement to a contrast correction method is applied to increase the Red colour by stretching red histogram towards the maximum (i.e., right side), similarly the Blue colour is reduced by stretching the blue histogram towards the minimum (i.e., left side). Thirdly, the Saturation and Intensity components of the HSI colour model have been applied for contrast correction to increase the true colour using Saturation and to address the illumination problem through Intensity. We compare our results with three well known methods, namely Gray World, White Patch and Histogram Equalisation using Adobe Photoshop. The proposed method has produced better results than the existing methods.**

***Keywords*— Contrast Correction, Image Enhancement, Colour Balancing, Colour Cast Correction.**

I. Introduction

Image enhancement techniques are used to make images lighter or darker, or to increase or decrease contrast, or to remove undesired characteristics of an image such as colour cast. Low contrast is considered a serious problem as it reduces the visual quality of digital images. This affects the clarity of resulting printouts, and further processing of these images. Presently, several software tools used in research and scientific laboratories as well as in industry are used to filter out the undesired characteristics. Most existing software tools used for image enhancement are semi automated, however, these tools are applied to normal images, and are not suitable for underwater images. They do not always work as expected with underwater images and videos. Learning to manipulate the colour in underwater images and videos through computer editing software requires patience and expertise. Consequently, automated methods, especially in underwater video enhancement for aquatic analysis, are highly desirable.

Different researchers have proposed different methods in order to address the problem of underwater image enhancement. However, the existing methods do not address the problem thoroughly. For example, [1], [2] have proposed a method by setting the predefined threshold values. This limits the scope of the approach and therefore the approach can not be applied to every kind of images [1], [2]. Every image has its own characteristic that makes such approaches unreliable.

In order to address the issue of light absorption, underwater vehicles are used which emit artificial light. However, this source of light introduces new problems. For example, artificial illumination tends to illuminate the scene in a non-uniform fashion. Furthermore, the movement of vehicles generates shadows in the scene [3]. Some algorithms require high computational cost in terms of time and resources [4], [5]. Physics based methods have also been used with lens filters. Filters cannot colour correct while shooting at depth in ambient light, where red and yellow wavelengths of light have significantly almost disappeared [6], [7]. Physics based approaches are not suitable for colour correction. In order to address the above issues, it is important to develop an image enhancement technique that can improve the quality of the underwater images by reducing colour cast and improving the contrast.

In this paper, we propose UCM for underwater image enhancement. The proposed approach is based on colour balancing, contrast correction of RGB colour model and

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contrast correction of HSI colour model. The rest of the paper is organised as follows: section 2 presents existing literature; section 3 discusses our proposed approach; section 4 discusses evaluation and provides results; section 5 presents discussion and section 6 concludes the paper.

II. EXISTING LITERATURE

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 colour channels [8], [9]. 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 colour 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 colour correction [10], [11]. 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 colour 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 neighbouring 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 [11]. Another similar technique was proposed by [12] which is known as "AQUA".

Physics based methods have also been used in lens filters to adjust the colour temperature by absorbing certain wavelengths of light. Therefore, such approaches ensure the quality of the captured images or videos are high. The contrast enhancements approaches can also be used in conjunction with lens filters [13]. Such approaches intend to decrease the effect of the scattering of light to achieve an enhanced underwater images or videos. The issue of backscatter can also be addressed using polarised filters [14]. Such techniques mainly focus on the recovery of the objects. They help to analyse and remove the physical effects of visibility degradation which can be associated with partial polarisation of light. The advantage of these approaches is that they are simple to use. However, the problem of using the lens filter is that they also absorb some sort of illumination and thus produce dark images. It is argued that illumination is already a major problem in underwater images. Therefore they are not suitable to be used for underwater image enhancement, and notably, they do not perform any colour correction. Such approaches are more suitable for common or land photography.

III. PROPOSED APPROACH

In this section, we describe our proposed approach, an Unsupervised Colour Correction Method (UCM), which can efficiently remove bluish colour cast, increase the low red and low illumination problem in order to achieve high quality images. Our proposed approach is based on the following three stages:

A. Equalisation of RGB colours

B. Contrast correction of RGB colour model

C. Contrast correction of HSI colour model

A. Equalisation of RGB colours

To achieve a good quality image requires the equal colour values of the RGB components. Unfortunately, in the underwater situation, images are rarely colour balanced correctly. In order to equalise the RGB value, the first step of the proposed approach is to calculate the maximum values. Let $I_R(i,j)$, $I_G(i,j)$ and $I_B(i,j)$ be respectively the red, green and blue components of an RGB image of size $M \times N$ pixels, Where $i = 1,\dots,M$; $j = 1,\dots,N$. The maximum pixel values of each colour component $R_{\max}$, $G_{\max}$ and $B_{\max}$ are calculated [15]:

$$R_{\max} = \max_{i,j} \quad I_R(i,j) \tag{1}$$

$$G_{\max} = \max_{i,j} \quad I_G(i,j) \tag{2}$$

$$B_{\max} = \max_{i,j} \quad I_B(i,j) \tag{3}$$

In the first step, the prominent colour cast channel is found using the above equations. Then the average values of each colour component R_{avg}, G_{avg} *and* B_{avg} are calculated [15]:

$$R_{avg} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} I_R(i,j) \tag{4}$$

$$G_{avg} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} I_G(i,j) \tag{5}$$

$$B_{avg} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} I_B(i,j) \tag{6}$$

The proposed method keeps the dominant colour cast channel constant since underwater images always have high blue colour as compared to other colours. Therefore high values are used to increase the other colours in order to make the image balanced. Based on dominant colour 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 [16].

$$A = B_{avg} / R_{avg} \tag{7}$$

$$B = B_{avg} / G_{avg} \tag{8}$$

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

$$R' = A \times R \tag{9}$$
$$G' = B \times G \tag{10}$$

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

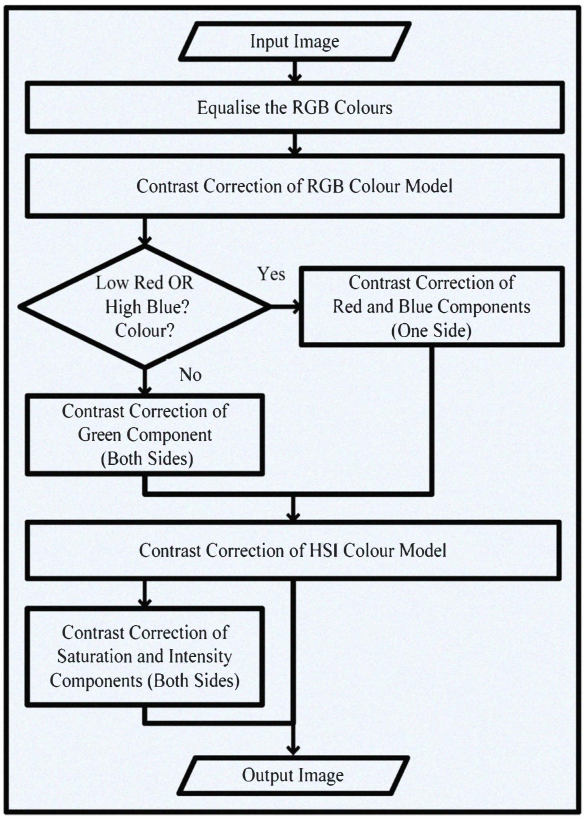

Figure 1: Flowchart of Proposed UCM Algorithm

B. *Contrast Correction of RGB Colour Model*

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 improve the contrast of an image. This is carried out by stretching 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 colour channel is 0-255. A common normalisation method is used to find the minimum and maximum pixel values in the histogram and stretch them between the specific range. A major problem with this method is that a single outlying pixel having too high or too low value can badly affect the image. This leads to unrepresentative scaling [17]. The problem can be solved through clipping (i.e., cut off few pixel values from both sides of the histogram) in order to obtain a clearer image. The proposed approach addresses the above problem by taking a histogram of the image and then selecting 0.2% and 99.8% as determinants [18]. This shows that the image can be enhanced by ignoring all the pixels values outside the range of 0.2% and 99.8% and only applying the contrast correction method to the inside pixel values as shown in Figure 2.

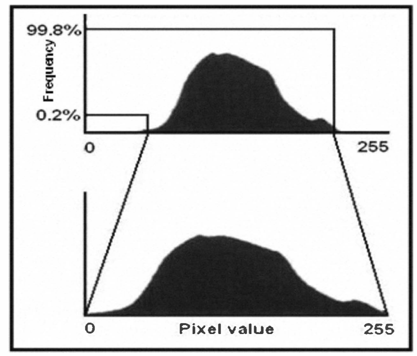

Figure 2: Contrast Correction Method [19]

1) 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 [20].

$$P_o = (P_i - c)\frac{(b-a)}{(d-c)} + a \tag{11}$$

Where,

- P_o is the contrast corrected pixel value;
- P_i 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.

2) Contrast Correction to Upper Side: Here, the lowest colour value component is selected; that is normally the red colour component which is the first colour 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 3. The formula 11 is modified to stretch the red colour component.

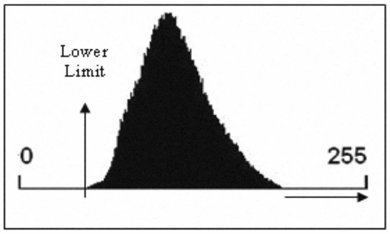

Figure 3: Contrast Correction to Upper Side

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.

3) Contrast Correction to Lower Side: In the second step, the prominent colour cast component is selected which has heavy colour cast and in underwater images that is the blue colour. Therefore, underwater images always have a bluish colour cast. For the adjustment of blue colour cast, the contrast correction method is applied toward minimum side to solve the problem of bluish colour cast as shown in Figure 4.

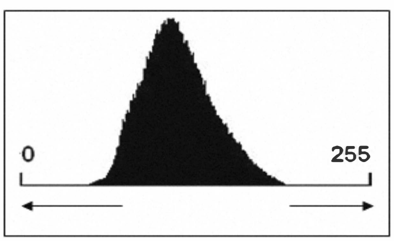

Figure 4: Contrast Correction to Lower Side

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.

4) Contrast Correction to Both Sides: Here, the proposed approach is applied to find the colour component which has the value between lower and higher colour components. In this case, adjustments are made toward both directions, minimum and maximum side, using contrast correction method. Such adjustments help to spread the histogram well to both directions as shown in Figure 5.

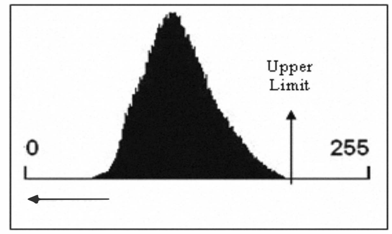

Figure 5: Contrast Correction to Both Sides

The contrast correction formula (4.11) 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

C. Contrast Correction of HSI Colour Model

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

1) Contrast Correction to Both Sides: Saturation and Intensity parameters of HSI colour model are used in contrast correction method. In this paper, these parameters are combined with RGB colour model for underwater image enhancement. In this case, the adjustments are made towards both directions, downward (toward dark side), and upward (toward bright side) using contrast correction method, as mentioned in section 3.2.4. Such adjustments help to spread the histogram well to both directions as shown in Figure 5.

The HSI colour model provides a wider colour range by controlling the colour element of the image. The Saturation and Intensity are the elements that generate a wider colour range. The blue colour 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

HSI colour model. Importantly, using the Saturation parameters, the true colour of the underwater image is obtained. Additionally, illumination is considered important for the underwater images. It is achieved using the Intensity parameter of the HSI colour model.

The above mentioned three stages are applied to every pixel of the image to produce the correct value for the pixel.

IV. Performance Evalution

In order to evaluate the performance of the proposed method, we compare our results with three existing methods, Gray World (GW), Adobe Photoshop Histogram Equalisation (APHE) and White Patch (WP). The comparison is carried out based on edge detection and histogram.

A. Edge Detection

Several researchers have used edge detection method in order to evaluate the performances of their methods based on the number of edges found in an image [21]. This is carried out by counting the number of edges detected using an automatic Sobel edge detector. Open source ImageJ software is used to detect the edges. The images having the maximum number of edges are regarded as having higher feature content. An auto-threshold value (85-175) is used to detect the edges. UCM has been able to detect more edges than the existing approaches as shown in Figures 6, 7 and 8. In many cases APHE method has generated noise and edge detector has detected noise as objects, as can be seen in Figure 7. Only three images are shown due to space limitation.

B. Histogram

An image histogram represents a graph that can be used to evaluate the quality of an image by comparing the values of an image before and after enhancement. However, there are few other factors that need to be taken into account in order to conduct evaluation. Several researchers have used the histogram as an analytical tool in order to evaluate the performance of their methods [4].

Our evaluation has taken into account the following guidelines which are derived from the existing literature. "The wider histogram represents a more visually appealing image" [22]. In order to achieve that, the histogram should be stretched to the minimum (0) and maximum (255) value level. It can be noted in Figures 6, 7 and 8 that the histograms generated by UCM images are stretched well to both minimum (0) and maximum (255) sides. Whereas the histograms generated by GW, APHE and WP are not fully stretched.

V. Discussion

This section discusses the results of our proposed approach: Unsupervised Colour Correction Method in relation to Gray World, White Patch and Adobe Photoshop Histogram Equalisation. It will discuss why the results obtained by the proposed approach are better than these achieved by existing approaches. This will be done by describing the key functions of each method and its impact on the quality of enhanced images.

A. Gray World (GW)

Results show that the GW method only performs well if an image is equally balanced otherwise it produces distortion or bad results. GW method is based on average values of all colours in an image; the average values can only be used to correct the affected image if all pixel values of each colour component are equally balanced. But unfortunately in underwater situation one colour always dominates an image. Therefore, the Gray World method is not suitable to enhance the heavy colour cast images (e.g. underwater images). It produces good results in low colour cast situation. Secondly, this method does not have any impact on brightness of an image. It only focuses on colour improvements. Thirdly this method does not enhance the contrast of an image.

B. White Patch (WP)

The WP method is based on the assumption that maximum values of each component should correspond to full illuminant, that means it should use the maximum of R, G and B values to estimate the illuminant. Based on the results it can be argued that in most of the cases the WP method does not have any visible effect on the image as this method estimates the colour of the illuminant by identifying the colour cast of the brightest pixel which may not be possible in a heavy colour cast situation.

C. Adobe Photoshop Histogram Equalisation (APHE)

The results show that the APHE method has been able to enhance the images with some limitations. APHE method equally distributes the intensity values over the intensity range. Results show that this method focuses on brightness of the image and does not produce good results especially if the images have dark or shadow region. Due to this factor, the enhanced images become over bright. In other words, it does not produce realistic images. Importantly, it does not remove the colour cast and therefore, it has adverse effects on colour cast images. It only equalises the values based on its fixed criteria without taking into account the nature of the image.

D. Unsupervised Colour Correction Method (UCM)

The results show that the proposed UCM method is able to enhance underwater images. UCM is based on three steps and each step is playing an important role in enhancing underwater images as briefly described below.

1) Balancing an image: Underwater images always have high blue colour as compared to other colours. Therefore this high values are used to increase the other colours in order to make the image balanced.

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

3) Improvement of illumination and increase of true colour: The illumination and true colour of underwater images have been increased through Intensity and Saturation parameters of HSI colour model. Therefore the images look brighter and richer in colours.

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 colour 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 colour cast such as land images.

VI. Conclusion

In this paper, we have discussed that underwater images are affected by high bluish colour cast, low red colour and low illumination problem due to absorption, turbidity and scattering of light in an aquatic environment. We have proposed an Unsupervised Colour Correction Method (UCM) approach for underwater image enhancement. Our approach is based on the contrast correction of RGB and HSI colour model. The proposed approach efficiently removes the bluish colour cast and improves the low red colour. It also improves the low illumination and true colours of underwater images. In order to evaluate the performance of the proposed method, we compared our results with the three existing methods, Gray World, Adobe Photoshop Histogram Equalisation and White Patch. The evaluation is based on edge detection and histogram. It has been shown that our proposed method obtained the best results compared to the existing ones.

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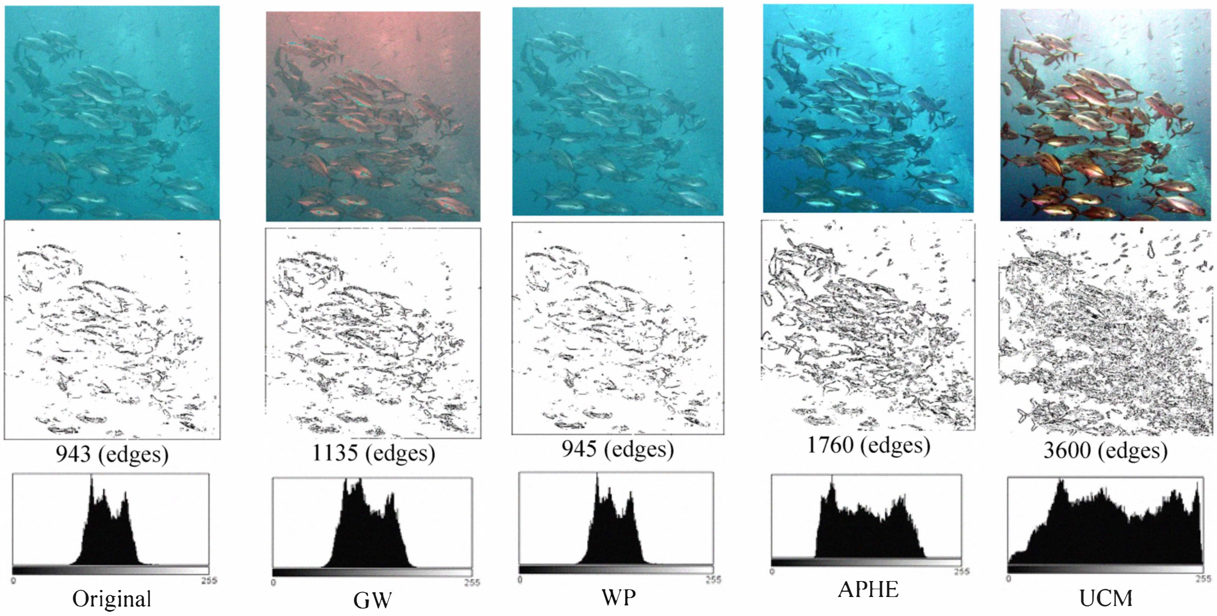

Figure 6: Results comparison before and after enhancement

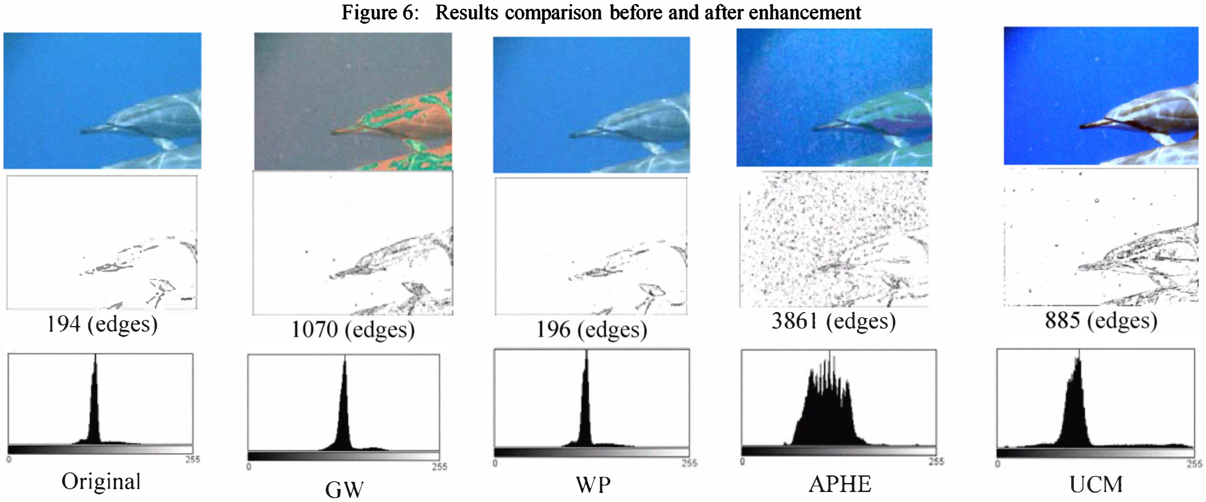

Figure 7: Results comparison before and after enhancement

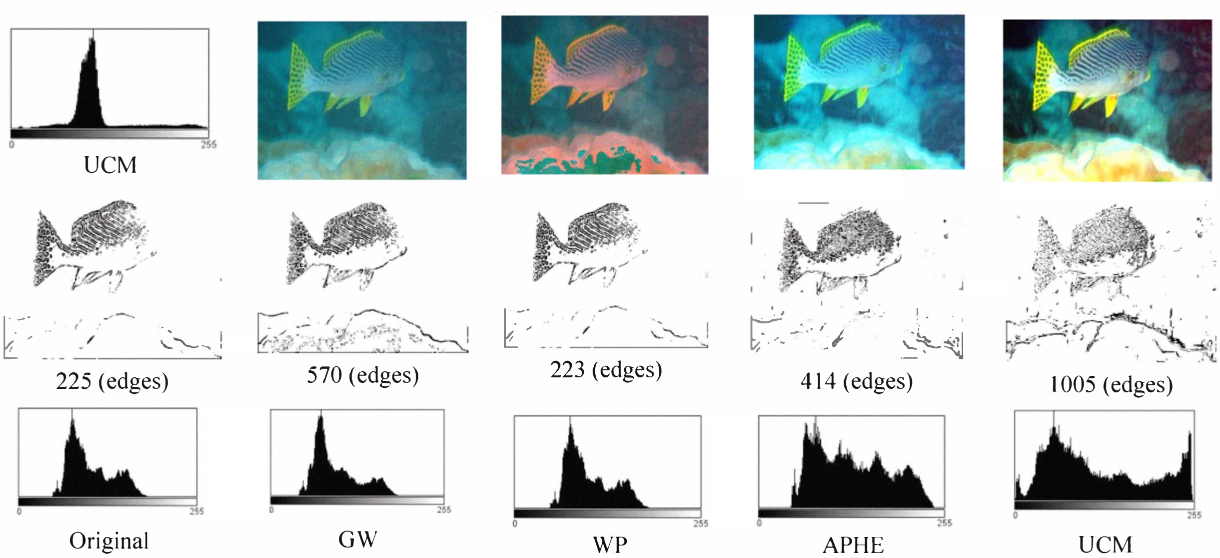

Figure 8: Results comparison before and after enhancement