AN ENHANCEMENT OF UNDERWATER IMAGES USING CLAHE AND FUSION

Khine Thin Zar*1, Thin Thin Hlaing*2, Su Su Maung*3

*1,2,3Department of Computer Engineering and Information Technology, Yangon Technological University, Yangon, Myanmar.

ABSTRACT

Underwater image enhancement techniques discard color cast, improve image contrast, reduce haze and restore the true color of degraded underwater images. There are various image enhancement techniques dedicated to the underwater environment. Among these techniques, this thesis chooses two methods called fusion and CLAHE (contrast limited adaptive histogram equalization). First, a total of 60 hazy underwater images are collected to use as a dataset, all resized to 300 x 400 pixels images. Then, CLAHE, which handles “light scattering”, “color change” effects and artificial lighting problems, is applied to hazy images. CLAHE is carried out in both RGB and HSV color spaces. After that, the fusion algorithm, with fast performance, is deployed onto the same dataset to restore clarity of the images. Output results of these methods are measured with entropy and UCIQE (underwater color image quality evaluation). According to the analysis values, fusion performs the best when compared with CLAHE in RGB space and CLAHE in HSV space. Implementation and evaluation of these two techniques are done with MATLAB.

Keywords: Image enhancement, underwater, fusion, CLAHE, entropy, UCIQE

I. INTRODUCTION

Underwater photography is the process of taking photographs underwater. Taking clear and colorful underwater images is very challenging. The water is usually turbid because of the presence of suspended particles in it. This causes haziness in underwater images. Another problem is that water absorbs light. The deeper the water, the more color and contrast of the image degrade. Light is not sufficient underwater, therefore, artificial light is used. This causes non-uniform lighting, a bright spot in the center of the image with a poorly illuminated area surrounding it. Due to all these conditions, underwater images have degraded quality with poor clarity and colorfulness, and may not be suitable for further uses.

Successful underwater images are usually taken with specialized equipment and techniques. However, using high-resolution cameras and lens may be an expensive solution. This is why there have been several researches for underwater image enhancement techniques. Underwater image enhancement techniques improve image contrast, remove the color cast and restore clarity. By enhancing degraded underwater images, they become useable for further research and studies.

Underwater image enhancement techniques are effective in ocean engineering, identification, and monitoring of marine species, finding shipwrecks and submerged cave systems, studying corals and reefs. Among several existing enhancement techniques, which are specifically developed for underwater environments, this paper evaluates two methods called fusion and CLAHE (Contrast Limited Adaptive Histogram Equalization).

It is very difficult to take underwater images because of the "light scattering effect", "color change effect" and insufficient light. "Light scattering effect" exists due to the presence of suspended particles such as bubble noises, small fishes, and small creatures in the underwater environment. This effect causes haze in the image which degrades visibility and causes low contrast of the captured image. The second problem is the "color change effect" caused by the attenuation of light. Light consists of different wavelengths. Different wavelength of light is attenuated by different degree of water. Shortest wavelength color (blue) travels longest in the water. This is why most of the underwater images are dominated by a bluish color. Sometimes, photographers use an artificial light source to overcome insufficient lighting in underwater but this artificial light source can cause overcompensating. It is better to remove artificial lighting and reconstruct an original image.

This paper describes and compares the CLAHE technique, which improves images by eliminating scattering and color change effect, and fusion technique, which is simple and perform relatively fast on any hardware.
II. METHODOLOGY

A lot of researchers are becoming more and more engrossed in underwater image enhancement techniques. There are research papers that express different enhancement algorithms and compare or evaluate one technique with others. This thesis elected to describe CLAHE and fusion techniques among existing enhancement techniques and to measure the outputs using two parameters: entropy and UCIQE. Figure 1 shows the general procedure of the proposed system.

![Diagram of proposed system]

**Figure 1:** General Procedure of the Proposed System.

A. CLAHE

CLAHE stands for contrast limited adaptive histogram equalization. It is similar to histogram equalization and adaptive histogram equalization. However, those two techniques tend to over-amplify noise in the output images. CLAHE is intended to overcome this problem by enhancing contrast on small data regions or tiles rather than the entire image. CLAHE uses a clip limit to avoid noise amplification. This system uses dark channel prior and CLAHE to correct color channels and to eliminate artificial light. Figure 2 shows the flow chart of the CLAHE algorithm [3].
B. Fusion

The main intention of the fusion method is to use only one degraded input image rather than combining multiple images taken from different depths or environments. The final output of this method depends on the choice of appropriate inputs and different weight maps. By combining inputs and weight maps, an enhanced output image, containing specific important information, can be constructed [1].

Figure 3 depicts the system diagram of the fusion technique. The original input is pre-processed using Red Channel Prior. The image is then applied white balancing and contrast stretching separately. Then, from these two inputs, luminance weight map, chromatic weight map and saliency weight map are generated respectively. Finally, two inputs and their corresponding weight maps are merged to give an enhanced output final image [2].
III. MODELING AND ANALYSIS

A. Dataset
Dataset holds 60 underwater images. The maximum size of the images is 300 x 400 pixels. Dataset is collected from a website called Flickr.com and, from a dataset to evaluate underwater image restoration methods, IEEE OCEANS 2016-Shanghai, 2016.

B. Failure of Dark Channel Prior in CLAHE
There may be some images that dark channel prior may not work correctly. This is because objects in the image are very similar to the background light and there is no cast shadow on them. In these cases, dark channel prior cannot calculate a precise depth map which leads to removing artificial light incorrectly and producing poorer outputs. Figure 4 shows a hazy underwater image with an inaccurate depth map and failed outputs of CLAHE. It would be wise to just apply CLAHE directly to these kinds of input images [4].
C. CLAHE in HSV Space versus CLAHE in RGB Space

Before comparing CLAHE and fusion, firstly, outputs of CLAHE in two different color spaces are analyzed to see their advantages over one another. Generally, there are three types of hazy underwater images. They are white-dominant images, bluish and greenish images. After experimenting with 60 underwater images, it was seen that for white-dominant inputs, applying CLAHE in HSV space can produce more vibrant and colorful images as shown in figure 5.

**Figure 5**: CLAHE on White Dominant Image (a) Input Hazy Image (b) Output of CLAHE in HSV Space (c) Output of CLAHE in RGB Space
As for greenish and bluish underwater images, CLAHE in HSV space can only improve contrast but cannot eliminate color cast as effectively as employing CLAHE in RGB space. Figure 6 and figure 7 illustrates applying CLAHE in RGB space is more suitable when it comes to greenish and bluish inputs.

![Figure 6: CLAHE on Green Dominant Image](image)

(a) Input Hazy Image  (b) Output of CLAHE in HSV Space  
(c) Output of CLAHE in RGB Space

**Figure 6:** CLAHE on Green Dominant Image (a) Input Hazy Image (b) Output of CLAHE in HSV Space  
(c) Output of CLAHE in RGB Space

D. CLAHE versus Fusion

When the image is extremely hazy with very little contrast and color information, CLAHE may not perform well in both color spaces while fusion can discard color cast effectively. Figure 8 shows how well fusion can remove color cast when compared with CLAHE.

![Figure 7: CLAHE on Blue Dominant Image](image)

(a) Input Hazy Image  (b) Output of CLAHE in HSV Space  
(c) Output of CLAHE in RGB Space

**Figure 7:** CLAHE on Blue Dominant Image (a) Input Hazy Image (b) Output of CLAHE in HSV Space  
(c) Output of CLAHE in RGB Space

(a)  
(b)
CLAHE also does not work well when the image carries so many details with similar colors to the background. As shown in figure 9, fusion can work with detailed images better than CLAHE.

Fusion may be the best at restoring color no matter how hazy or how detailed the input may be. However, it may lose the sense of depth which is important to human perception when viewing distant objects. Output images with no sense of depth may sometimes feel odd to the viewer. It may also be difficult to estimate the
distance between objects in the image, or distance between objects the viewer. An example of this case can be seen in figure 10.

![Images of underwater scenes with different processing methods]

**Figure 10**: Importance of Haze in indicating depth (a) Input Image (b) Output of Fusion (c) Output of CLAHE in HSV Space (d) Output of CLAHE in RGB Space

Fusion technique generates vibrant, colorful images that may be unnatural in some images. In figure 11, CLAHE in RGB space gives a much more believable color when compared with fusion.

Regarding the presence of artificial light, fusion algorithm overlooks this problem. This may cause overexposure in artificially illuminated regions of the image. CLAHE can handle this problem by removing artificial light before applying CLAHE method onto the image. Figure 12 is a good example to demonstrate this problem.
Figure 11: (a) Input Image (b) Output of Fusion (c) Output of CLAHE in HSV Space (d) Output of CLAHE in RGB Space

Figure 12: Enhancing an Artificially Illuminated Image (a) Input Image (b) Output of Fusion (c) Output of CLAHE in HSV Space (d) Output of CLAHE in RGB Space
The last observation encountered when experimenting would be the reddish appearance in fusion outputs. When compared with the outputs of CLAHE, fusion outputs may have red artifacts showing in some regions despite the use of red channel prior as seen in figure 13.

IV. RESULTS AND DISCUSSION

To examine the quality of output images, two methods called entropy and UCIQE are utilized. Both of these methods do not need an original hazy underwater image (as a reference image) to be compared with output. In this research, they are applied onto output enhanced images and the original image (to show the improvement more clearly in tables and graphs).

A. Entropy

Entropy specifies the amount of information retained in an output image. The high value of entropy states that the amount of distortion in the final image is less. Entropy of an image can be calculated as

\[
\text{Entropy} = -\sum_{i=1}^{n} p_i \log_2 p_i
\]  

(1)

where \( p_i \) is the occurrence probability of a given pixel;

\[
p_i = \frac{\text{Number of occurrences of the intensity level } i}{\text{Number of intensity levels}}
\]

(2)

Entropy values of 60 underwater images are calculated and average values can be seen as shown in table 1. Table 1 describes the average entropy values of original images and two enhancement techniques: CLAHE (in both HSV and RGB color spaces) and fusion.

<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>CLAHE (HSV)</th>
<th>CLAHE (RGB)</th>
<th>Fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>6.55</td>
<td>6.89</td>
<td>7.04</td>
<td>7.72</td>
</tr>
</tbody>
</table>

Higher entropy value designates better image quality. As seen in the bar graph (figure 14), all enhancement techniques show better entropy values than the original hazy image. Fusion method has the highest entropy value when compared with CLAHE.
B. UCIQE

UCIQE stands for underwater color image quality evaluation. This metric is specifically used for underwater image evaluation. UCIQE quantifies the non-uniform color cast, blurring and, low-contrast. It evaluates underwater image quality according to human perceptions. The image is converted into CIELab space and $L_p$, $a_p$ and $b_p$ be the intensity values in the $L$, $a$ and $b$ respectively. UCIQE is calculated by using

$$UCIQE = c_1 \cdot \sigma_c + c_2 \cdot con_l + c_3 \cdot \mu_s$$

(3)

where $con_l$ = contrast of luminance, that is the difference between the maximum and minimum intensity value of the $L$ channel.

$\sigma_c$ = standard deviation of chroma,

$$\sigma_c = \frac{1}{N} \sum_{p=1}^{N} (C_p^2 - \mu_c^2)$$

(4)

with chroma, $C_p$

$$C_p = \sqrt{a_p^2 + b_p^2}$$

(5)

$\mu_s$ = average of saturation,

$$\mu_s = \frac{1}{N} \sum_{p=1}^{N} S_p$$

(6)

with saturation, $S_p$ defined as

$$S_p = \frac{C_p}{L_p}$$

(7)

c_1, c_2 and c_3 are weighted coefficients ($c_1 = 0.4680, c_2 = 0.2745, c_3 = 0.2576$) [16].

Figure 14: Comparison of Entropy Values for Original Images and Different Underwater Enhancement Techniques
For this system, UCIQE is applied to 60 sample images and their average results are measured. Table 2 shows the average UCIQE values of original images and two enhancement techniques: CLAHE (in both HSV and RGB color spaces) and fusion.

<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>CLAHE (HSV)</th>
<th>CLAHE (RGB)</th>
<th>Fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCIQE Values of Original Images and Different Underwater Enhancement Techniques</td>
<td>24.65</td>
<td>28.83</td>
<td>29.31</td>
<td>32.18</td>
</tr>
</tbody>
</table>

Image with more excellent quality has higher UCIQE values. As described in figure 15, it can be seen that all enhancement techniques have greater UCIQE values than the original. Among all the enhancement techniques, fusion shows the highest UCIQE.

Figure 15: Comparison of UCIQE Values for Original Images and Different Underwater Enhancement Techniques

Amongst two color spaces, applying CLAHE on HSV is much suitable for white-dominant images while enhancing RGB images CLAHE works well with greenish or bluish inputs. There may be some cases that CLAHE should be applied directly without the use of the dark channel prior because the objects in the image are difficult to separate from the background.

Fusion performs really well in eliminating color casting and works on almost all images. However, its outputs have no sense of depth and may have an unnatural color scheme. It may over-compensate artificially illuminated regions and may appear slightly reddish in those regions.

Regarding the processing time, fusion requires only single input and relatively faster than CLAHE. On the other hand, CLAHE's processing time depends on the size of the input image. The larger the image size, the slower the processing time of CLAHE.

According to the measurements of the outputs of two techniques, fusion gives the best values in both entropy and UCIQE.

V. CONCLUSION

This enhancement system performed CLAHE and fusion on 60 underwater images. The methods are implemented and tested using MATLAB 2019a. Hazy underwater images are successfully enhanced with chosen methods. Each method is evaluated with two parameters: entropy and UCIQE. The analyzed results are stated clearly with tables and bar graphs. Fusion is better than CLAHE when looked at these graphs, however, each algorithm has its own good and bad points. CLAHE handles the problem of artificial light which fusion neglects. Fusion is faster and more robust than CLAHE.
VI. REFERENCES


