Homomorphic filtering with image fusion for enhancement of details and homogeneous contrast of underwater image

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The proposed method modified the integration of emphasis homomorphic filtering and image fusion (HFIF) to address these problems. Emphasis homomorphic filtering is equipped with the ability to reduce inhomogeneous illumination in an image by increasing the high frequency image signals and reducing or removing low frequency unwanted illumination. Further, the image is applied with histogram matching to increase the influence of inferior color channel while decreasing the dominant color channel. This will automatically balances the color percentages of the image. The image is further processed through enhanced dual-images fusion to improve the overall image contrast and increases the saturation and brightness of the image. Finally, the input image will go through contrast limited adaptive histogram specification to improve the image contrast locally and reduces the effect of under- and over-enhanced areas. Quantitative and qualitative results prove that the new method has outperformed the other state-of-the-art methods in terms of contrast and image detail. Nevertheless, the aforementioned problems have been significantly reduced. Image color is also highly improved.

[Keywords: homomorphic filtering; dual-image fusion; histogram matching; underwater image.]

Introduction

Underwater image suffers from several problems such as low color and contrast, low visibility and detail, blue-green illumination effect, and under- and over-enhanced effects. The problems result in limited usage of the images. In terms of detection, the objects in the image are hardly seen and not detectable while having low possibility of tracing.

Image enhancement is a process of improving an image based on qualitative perspective of human visual system¹. This process is simpler than image restoration which required some equations, coefficients, or parameters in improving image quality. This technique has attracted considerable attention in recent years and results in introduction of various techniques to improve underwater image for further usage. Most of the researchers in underwater image processing use this technique to improve the image because of its simplicity and normally faster than restoration method as it does not require any coefficient or parameters.

In this paper, a new method to improve underwater image has been introduced. The new HFIF method integrates homomorphic filtering and image fusion to produce better output image especially in terms of homogeneous contrast, detail, and visibility. The new HFIF method aims to improve the underwater images for shallow water applications where the availability of natural illumination from the sun is aplenty. The rest of this paper is organized as follow: Section 2 discusses the related work in the areas of the new method; Section 3 describes the motivation of the new method; Section 4 presents the new HFIF method in detail; Section 5 demonstrates the qualitative and quantitative results in comparison with other state-of-the-art methods; Section 6 concludes the paper and the new method. Apart from underwater images, the normal images which are captured in normal air condition are also used in the test. Samples of these normal images are included in Appendix.

Materials and Methods

In most of the cases, the captured underwater images are suffered with some problems such as non-
uniform illumination, blue-green illumination, and under- and over-enhanced areas. Normally, the captured image seems bright near to the capturing devices. However, as the captured areas are far from the capturing device, the brightness of the image will be gradually decreased. This results the captured image to seem bright at the foreground but darker at the background. On the other hand, captured images with artificial flash application usually have the bright spot at the middle of the image and the brightness is gradually decreased as it farther from the image center. Previous works have been proven that the combination of several enhancement techniques is required to improve the overall image quality. In this new method, the improvement is focused on homogeneous contrast, visibility, and image detail as they are the most essential and important factors that used in detection, recognition, and tracking objects underwater especially for underwater robots.

In the new method, homomorphic filtering is designed using the high-pass filter to reduce or eliminate inhomogeneous illumination in an image. In illumination-reflectance model, image, \( I(x,y) \) is regarded as the multiplication of reflectance, \( R(x,y) \) and illumination, \( L(x,y) \).

\[
I(x,y) = R(x,y) \ast L(x,y)
\]  

(1)

In this model, illumination, \( L(x,y) \) which is regarded as noise signal should be removed. Therefore, to remove the illumination, the multiplicative component of \( R(x,y) \ast L(x,y) \) should be first converted into additive components by transforming into log domain. Thus,

\[
\ln(I(x,y)) - \ln(R(x,y) \ast L(x,y))
\]  

(2)

\[
\ln(I(x,y)) = \ln(R(x,y)) + \ln(L(x,y))
\]  

(3)

Illumination component is regarded as low-frequency signal that needs to be removed. For that reason, high-pass filter, \( H(u,v) \) is used to remove low-frequency illumination while preserving the high-frequency reflectance component. The Butterworth filter is used to filter the low-frequency signal. In most of the cases, homomorphic filtering is normally applied to gray-image\(^2\). The new method is designed to integrate the homomorphic filtering with image enhancement which includes the histogram modification. This integration is new as inhomogeneous illumination is normally increased or become more visible after the enhancement process. Inhomogeneous illumination normally results the output image to become unbalance contrast. Some of the previously proposed methods show that some parts of the output images are darker than the other parts. Others show that some areas are observed greener or bluish from other parts. Thus, based on these observations, before applying image enhancement process, the image in the new HFIF method will undergo homomorphic filtering process.

While homomorphic filter is used to reduce or eliminate inhomogeneous illumination, the tested underwater images are still suffered from blue-green illumination and low contrast. To overcome these problems, the images are further processed with histogram matching to increase the influence of inferior color channel. Instead of equalizing the image intensity by applying Von Kries hypothesis as implemented by Iqbal et al.\(^3\), the use of histogram matching reduces the image color distortion as resulted by Von Kries hypothesis. In the proposed method, the inferior and intermediate color channels are matched with the dominant color channel. The matching process will automatically increase the influence of the inferior and intermediate color channels and decreased the dominant color channel. Thus, blue-green illumination will be reduced as all color channels are almost equally distributed through the image and have approximate identical percentages.

Nevertheless, although the effects of inhomogeneous and blue-green illuminations are reduced, the dark areas in in some of the image are retained. To reduce the dark areas, the image is implemented with Rayleigh-stretching and averaging image planes\(^4\) with integration of wavelet fusion. The method of Rayleigh-stretching and averaging image planes is proven to improve the image contrast and color globally. Through this method, image histogram will be divided at mid-point of intensity level and both sides of the histogram will be stretched independently with respect to Rayleigh distribution to produce two images. In addition to the new method, the combination of the produced images is done using fusion method based on 2D discrete wavelet transform (DWT), namely 2D-DWT. In 2D-DWT, spatial-spectral resolution is dependent on the
As shown in Figure 1, the high frequency bands show the detailed information of the original image which is normally used for edge and corner detection. This will be also useful to improve the underwater image detail.

As mentioned by Eustice et al., Hitam et al., and Abdul Ghani and Mat Isa, contrast limited adaptive histogram specification (CLAHS) is one of the best methods for local contrast improvement. Thus, in the new HFIF method includes a step of CLAHS for better improvement of local image contrast. This method corrects the image contrast from having extreme values of under- and over-enhanced areas adaptively.

Figure 2 illustrates the overall new HFIF method. HFIF begins with implementation of emphasis homomorphic filtering to the input image. As explained in the previous section, emphasis homomorphic filtering consists of applying Butterworth high pass filter in logarithm domain. This step is designed for reduction of inhomogeneous illumination which suffers by almost all underwater images. The image is then applied with histogram matching where the inferior color channel is mapped to the dominant color channel. This step increases the influence of inferior color channel and reduces the influence of dominant color channel as well. Enhanced dual-image fusion is applied to the image to increase the overall image contrast and improves image saturation and brightness. As the final step, the image will go through local contrast correction where the histogram of the image is modified within smaller tiles.

**Emphasis Homomorphic Filtering**

As reported by (Mathworks, http://blogs.mathworks.com/steve/2013/07/10/homomorphic-filtering-part-2/), implementation of homomorphic filtering results in lowering the image contrast. Therefore, a modified version of homomorphic, $H_\alpha(u,v)$ which is called high-frequency emphasis filter is used by adding an offset value and a scaling factor as follow:

$$H_\alpha(u,v) = \alpha + \beta H(u,v), \quad \alpha < 1, \beta > 1$$

As recommended by (Mathworks, http://blogs.mathworks.com/steve/2013/07/10/homomorphic-filtering-part-2/), the value of $\alpha$ is 0.5 and the value of $\beta=1.5$. Through the emphasis filter, the resulting gray-level image is sharper and has better contrast.

According to Figure 3, through homomorphic filtering, the image is first converted into logarithm domain to ensure the low-frequency illumination could be separated from reflectance component. The image is then applied with high-pass filter which required the image to be applied with Fast Fourier Transformation (FFT) before applying the Butterworth filter. Then, the image is applied with inverse FFT and exponential function to invert back the logarithm transformation and obtains a homomorphic filtered image.

Through the implementation of the emphasis filter to underwater color image, it is observed that inhomogeneous illumination is significantly reduced. However, darker image is obtained especially at the areas where the original image is under-enhanced. Thus, the image detail and image contrast at these areas is theoretically reduced. In addition, the tested underwater images are color images instead of gray-image as it is usually used. On the other hand, it cannot be denied that the dominant blue and green colors as well as green-blue illumination contribute towards the darkening the image.
Fig. 2—The overall process flow of the new HFIF method

Fig. 3—Process flow of homomorphic filtering.
Fig. 4—Illustration process of histogram matching

Fig. 5—Process flow of dual-image fusion

Fig. 6—Example of dividing process of CLAHS
Histogram Matching

To reduce the influence of dominant color channel and increases the influence of inferior color channel, the histogram of inferior color channel is matched with the histogram of dominant color channel. Through histogram matching, the probability distribution function (PDF) and cumulative distribution function (CDF) of both source and target histograms are required. PDF is given as the probability of occurrence of a gray-level value in an image.

Histogram matching is a transformation of an image histogram (i.e. source/input histogram) into another histogram (i.e. target/reference histogram) that aims to produce the source histogram with the distribution of reference histogram. The CDF of the target histogram will be matched with the histogram of the reference histogram by means of transformation function, \( s = T(r) \). In order to match these CDFs, the PDF of respective histogram should be obtained. Histogram of an image is given by \( h(r_k) = n_k \), where \( r_k \) is the k-th intensity-level and \( n_k \) is the number of pixels in the image having intensity level \( r_k \). Normalized histogram is given by \( p(r_k) = n_k/n \). \( n \) is the total number of pixel. If \( f(i) \) is a PDF of an image histogram, then,

\[
\int_{-\infty}^{\infty} f(i) = 1, \quad f(i) \geq 0 \quad \forall \quad i
\]

CDF of the image which is denoted as \( F(x) \) is given as the summation of PDF. Thus,

\[
F(x) = \sum_{i=-\infty}^{x} f(i)
\]

A transformation function, \( s = T(r) \) which is based on both source and reference CDFs will be obtained to map the intensity value, \( r \) of the source image, \( f(x,y) \) to the intensity value, \( s \) of the target image, \( g(x,y) \) at point of \( (x,y) \). Figure 4 illustrates the process of histogram matching.

Enhanced Dual-image Fusion

Low contrast image which is produced from the previous step will be enhanced in this step. The image will go through the process of dual-image fusion where two images will be produced from a single image. These images are obtained by dividing the image histogram at the mid-point and both produced regions are stretched independently to the entire dynamic range. The process of dividing and stretching of image histogram are explained in detail by Abdul Ghani and Mat Isa. Both produced images are integrated based on average value for both details and contrast using wavelet fusion method. Both produced images are applied with 2D-DWT to perform the wavelet decomposition. The approximation and details of the wavelet method should be selected to mean value. The synthesized image will be obtained from the fusion through inverse 2D-DWT.

Local Contrast Correction

As the final process step, the local contrast of the image will be corrected through contrast limited adaptive histogram specification (CLAHS) which divides the image into smaller tiles. Each tile will be processed independently. CLAHS consists of four main steps which are division of image into tiles, applying clip-limit, mapping the pixel distribution into Rayleigh distribution, and combination of tiles by means of bilinear interpolation. Shaik et al. have explained the detail about CLAHS process. Figure 6 illustrates the dividing example of image into smaller tiles to build individual tile histogram.

Results and Discussion

To evaluate the improvement of the new HFIF method, qualitative and quantitative measurements are done. However, it should be emphasized that, qualitative evaluation through human visual system (HVS) is the main evaluation method used to evaluate the image. Quantitative measurement is included to support the visual observation of HVS. In addition, quantitative measurement is not always agreed with HVS. In this case, the HVS should be taken as higher priority in the evaluation. In terms of qualitative evaluation, criteria such as contrast, color, blue-green illumination, and under- and over-enhanced areas are
taken into consideration. Resultant images will be observed if these problems are retained. On the other hand, in terms of quantitative evaluation, entropy, natural image quality evaluator (NIQE)\(^{11}\), measure of enhancement (EME)\(^{12,13}\) and measure of enhancement by entropy (EMEE)\(^{14}\) are used. A high value of entropy, EME, and EMEE is desired as it demonstrates the better image quality. On the other hand, low value of NIQE is desired as it indicates better image quality. Entropy \(H(x)\) is given by Equation (7). Here, \(p(x)\) represents the probability distribution function of the image at the state \(x\) (pixel). \(k\) is the total number of intensity level.

\[
H(x) = -\sum_{x=1}^{k} p(x) \log_2 p(x) \tag{7}
\]

NIQE, \(D\) is applied by computing the 36 identical features patches of the same size \(P \times P\) from the image to be quality analyzed, fitting them with the multivariate Gaussian (MVG) model, then comparing its MVG fit to the natural MVG model\(^{11}\). In the implementation of the NIQE, the patch size was set to 96 \(\times\) 96 as implemented by the authors in their researches. However, the stable performance across patch sizes ranging from 32 \(\times\) 32 to 160 \(\times\) 160. Thus, the quality of an image, \(D\) is expressed as the distance between the quality aware natural scene statistic (NSS) feature model and the MVG fit to the features extracted from the distorted image.

\[
D = \left(\frac{\sum_{1}^{k} \left\{ \frac{I_{\max,k,l}(\Phi)}{I_{\min,k,l}(\Phi)} \right\}^\alpha}{\sum_{1}^{k} \left\{ \frac{I_{\max,k,l}(\Phi)}{I_{\min,k,l}(\Phi)} \right\}^{\alpha + c}} \right)^{-1} \tag{8}
\]

If an image \(x(n,m)\) is split into \(k_1 \times k_2\) blocks of size \(I_1 \times I_2\), EME of the image for a given class \(\{\Phi\}\) of orthogonal transforms, is given by Equation (9).

\[
EME = \frac{1}{k_1 \times k_2} \sum_{i=1}^{k_1} \sum_{l=1}^{k_2} 20 \log \frac{I_{\max,k,l}(\Phi)}{I_{\min,k,l}(\Phi)} + c \tag{9}
\]

where \(I_{\min,k,l}(\Phi)\) and \(I_{\max,k,l}(\Phi)\) are the minimum and maximum intensity levels of the image \(x(n,m)\) inside the block after processing the block by \(\Phi\) transform based enhancement algorithm. \(c\) is a small constant which is equal to 0.0001 to avoid dividing by 0. Measure of enhancement by entropy (EMEE) is an extension of EME. EMEE is given by Equation (10)\(^{14}\). \(\alpha\) is a constant and equivalent to 0.8 as suggested by the authors. The high value of EMEE indicates the better image quality.

\[
EMEE = \frac{1}{k_1 \times k_2} \sum_{i=1}^{k_1} \sum_{l=1}^{k_2} 20 \log \frac{I_{\max,k,l}(\Phi)}{I_{\min,k,l}(\Phi)} + c \tag{10}
\]

Images coral brown and yellow stone in Figures 7 and 8 are used as samples to describe the improvement of the new method in comparison with state-of-the-art methods.

Visual observation in Figure 7 shows that the original image brown coral suffers from blue-green illumination and inhomogeneous illumination problems as the areas on the right side of the image are darker than the areas at the left side of the image. CLAHE-Mix and PDSCC methods could not significantly improve the images contrast as blue-green illumination retains in the output images. UCM produces brownish image. ICM improves image contrast better from the aforementioned methods, but fails to reduce the effect of inhomogeneous illumination. The right areas of the image are seen darker than the left areas of the image. CLAHS improves the non-uniform illumination and image contrast to some extend but it reduces the image color. Saturation and brightness of the image are clearly reduced in the resultant image and an amount of blue-green illumination retains in the image. HE, on the other hand enhances the image partly as the areas on the right side is better improved while the areas on the left side are over-enhanced. The new HFIF method has properly enhanced the image as blue-green illumination and the effect of inhomogeneous illumination have been reduced. The contrast and color are better improved.

The identical effects of resultant image are also observed in the image of yellow stone in Figure 8. As observed, the new HFIF method has significantly improved the images contrast and color. Blue-green illumination has been greatly reduced and the objects in the image are better differentiated from the background.

Apart from the visual observation, images are also evaluated through quantitative measurement in terms of entropy, NIQE, EME, and EMEE as shown in Tables 1 and 2. In terms of entropy, all sample images
and the average of 300 underwater images shows that the new HFIF method produces the highest value. This indicates that the new method produces the highest image details compared to the other methods. On the other hand, the values of EME and EMEE show that the new method produces the highest average values which are 33.660 and 15.767 respectively. In addition, three out of four sample image show that the new method produces the highest values of these quantitative evaluations. Nevertheless, the new method produces high value of NIQE which indicate that the quality of the image is not significant. However, visual observation has been proven that the new method produces the best resultant image and outperforms the other state-of-the-art methods.

Apart from the underwater images, the method is also tested with normal images which are captured in normal air condition. The samples of these images are included in Appendix. Some other underwater images are also included in Appendix.

<table>
<thead>
<tr>
<th>Method</th>
<th>Resultant image of brown coral</th>
<th>3D RGB color model of brown coral</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Original image</td>
<td><img src="image1" alt="Original image" /></td>
<td><img src="image2" alt="3D RGB color model" /></td>
</tr>
<tr>
<td>(b) CLAHE-Mix</td>
<td><img src="image3" alt="Resultant image" /></td>
<td><img src="image4" alt="3D RGB color model" /></td>
</tr>
</tbody>
</table>
Fig. 7—Image of brown coral. Images (a) are the original images of brown coral and the others are the resultant images of the following methods; (b) CLAHE-Mix, (c) PDSCC, (d) UCM, (e) ICM, (f) CLAHS, (g) HE, and (h) HFIF.

<table>
<thead>
<tr>
<th>Method</th>
<th>Resultant image of yellow stone</th>
<th>3D RGB color model of yellow stone</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Original image</td>
<td></td>
</tr>
</tbody>
</table>
(b) CLAHE-Mix

(c) PDSCC

(d) UCM

(e) ICM
Fig. 8—Image of yellow stone. Image (a) is the original image of yellow stone and the others are the resultant images of the following methods; (b) CLAHE-Mix, (c) PDSCC, (d) UCM, (e) ICM, (f) CLAHS, (g) HE, and (h) HFIF.

<table>
<thead>
<tr>
<th>Image</th>
<th>Method</th>
<th>Entropy</th>
<th>NIQE</th>
<th>EME</th>
<th>EMEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown coral</td>
<td>Original image</td>
<td>7.240</td>
<td>3.503</td>
<td>17.674</td>
<td>2.101</td>
</tr>
<tr>
<td>Brown coral</td>
<td>CLAHE-Mix</td>
<td>6.967</td>
<td>3.624</td>
<td>15.461</td>
<td>1.679</td>
</tr>
<tr>
<td>Brown coral</td>
<td>PDSCC</td>
<td>7.198</td>
<td><strong>3.448</strong></td>
<td>14.993</td>
<td>1.347</td>
</tr>
<tr>
<td>Brown coral</td>
<td>UCM</td>
<td>7.526</td>
<td>3.528</td>
<td>22.798</td>
<td>3.407</td>
</tr>
<tr>
<td>Brown coral</td>
<td>ICM</td>
<td>7.468</td>
<td>3.486</td>
<td>27.901</td>
<td>7.448</td>
</tr>
<tr>
<td>Brown coral</td>
<td>CLAHS</td>
<td>7.392</td>
<td>3.701</td>
<td>2.701</td>
<td>3.309</td>
</tr>
<tr>
<td>Brown coral</td>
<td>HE</td>
<td>5.975</td>
<td>3.693</td>
<td>23.450</td>
<td>6.097</td>
</tr>
<tr>
<td>Brown coral</td>
<td>HFIF</td>
<td><strong>7.835</strong></td>
<td>17.009</td>
<td><strong>40.029</strong></td>
<td><strong>26.611</strong></td>
</tr>
</tbody>
</table>
### Conclusion

The new HFIF method has integrated the homomorphic filtering with enhanced dual-image fusion and contrast limited adaptive histogram specification techniques to produce homogeneous contrast for underwater color images. As shown in qualitative and quantitative evaluations, it has been proven that the new method has successfully improved image contrast and detail by reducing the effect of blue-green and inhomogeneous illuminations. Objects in the image are better differentiated resulting in better objects identification. Nevertheless, the new method is concentrated on the images that are captured in shallow water. However, the enhancement of the image contrast is not effectively applied to images which are captured in deep sea water as the images have very high percentage of blue-green illumination. On the other hand, red color channel is entirely absorbed by water medium. In addition, the objects in the images are hardly seen and differentiated from the background. Reflecting these limitations however will be focused as further potential development of the research.

### Acknowledgement

This work is partially supported by the Fundamental Research Grant Scheme (FRGS), Ministry of Higher Education Malaysia, entitled “Formulation of a robust framework of image enhancement for non-uniform illumination and low contrast images”.

### References


### TABLE 2: Average Quantitative Values of 300 Tested Underwater Images in terms of Entropy, NIQE, EME, and EMEE

<table>
<thead>
<tr>
<th>Method</th>
<th>Entropy</th>
<th>NIQE</th>
<th>EME</th>
<th>EMEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original image</td>
<td>7.157</td>
<td>3.823</td>
<td>17.363</td>
<td>3.562</td>
</tr>
<tr>
<td>CLAHE-Mix</td>
<td>7.124</td>
<td>3.627</td>
<td>17.302</td>
<td>2.086</td>
</tr>
<tr>
<td>PDSCC</td>
<td>7.053</td>
<td>3.982</td>
<td>10.029</td>
<td>0.947</td>
</tr>
<tr>
<td>UCM</td>
<td>7.600</td>
<td>4.037</td>
<td>19.730</td>
<td>4.936</td>
</tr>
<tr>
<td>ICM</td>
<td>7.608</td>
<td>3.915</td>
<td>21.642</td>
<td>5.966</td>
</tr>
<tr>
<td>HE</td>
<td>5.893</td>
<td>3.538</td>
<td>22.911</td>
<td>5.387</td>
</tr>
<tr>
<td>HFIF</td>
<td>7.831</td>
<td>5.763</td>
<td>33.660</td>
<td>15.767</td>
</tr>
</tbody>
</table>

### Conclusions

The new HFIF method has integrated the homomorphic filtering with enhanced dual-image fusion and contrast limited adaptive histogram specification techniques to produce homogeneous contrast for underwater color images. As shown in qualitative and quantitative evaluations, it has been proven that the new method has successfully improved image contrast and detail by reducing the effect of blue-green and inhomogeneous illuminations. Objects in the image are better differentiated resulting in better objects identification. Nevertheless, the new method is concentrated on the images that are captured in shallow water. However, the enhancement of the image contrast is not effectively applied to images which are captured in deep sea water as the images have very high percentage of blue-green illumination. On the other hand, red color channel is entirely absorbed by water medium. In addition, the objects in the images are hardly seen and differentiated from the background. Reflecting these limitations however will be focused as further potential development of the research.

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### References


ABDUL GHANI and MAT ISA: HOMOMORPHIC FILTERING WITH IMAGE FUSION

(2002), Tokyo, Japan, pp. 141-145.

Appendix

<table>
<thead>
<tr>
<th>Original image 1</th>
<th>CLAHE-Mix</th>
<th>PDSCC</th>
<th>UCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICM</td>
<td>CLAHS</td>
<td>HE</td>
<td>HFIF</td>
</tr>
<tr>
<td>Original image 2</td>
<td>CLAHE-Mix</td>
<td>PDSCC</td>
<td>UCM</td>
</tr>
<tr>
<td>ICM</td>
<td>CLAHS</td>
<td>HE</td>
<td>HFIF</td>
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</table>