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UNDERWATER IMAGE ENHANCEMENT USING ADAPTIVE FILTERING FOR ENHANCED SIFT-BASED IMAGE MATCHING

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ABSTRACT

Success of scale-invariant feature transform (SIFT) image registration is limited when attempted on camera footage taken under water. This is, largely due to the poor image quality inherent to imaging in aquatic environments. In this research we aim to overcome this shortcoming using a new method of pre-processing of true-color imagery taken under water based on the Contrast Limited Adaptive Histogram image Equalization (CLAHE) algorithm. CLAHE assumes that the distribution function of the pixel intensity values of an underwater-recorded image is dominated by Rayleigh scattering, and that the noise can be removed as a function hereof. Results showed that after applying the CLAHE image enhancement method registration success of SIFT increased by 41% compared to reference method (a straightforward contrast stretching enhancement). From the ANOVA results follows that the null hypothesis can be rejected and concluded that there is a significant difference among SIFT without enhancement, SIFT with contrast stretching and SIFT with CLAHE-Rayleigh at 5% level of significance (ANOVA, F=23.41, df=2, p-value=7.34e-09). The finding concludes that CLAHE-Rayleigh is better compared to contrast stretching. As a follow-up study, CLAHE-Rayleigh should be compared with other image enhancement techniques (or a combination of techniques 'hybrids') to assess their relative impact on the success of SIFT-based image matching of underwater photography.

Keywords: *CLAHE, Image Enhancement, Image Registration, Underwater Image Processing, SIFT.*

1. INTRODUCTION

With the advances in underwater robotics seafloor cover mapping is becoming a cost-effective technology for a variety of applications, from cultural heritage inventories of submerged archeological sites to environmental monitoring of critically endangered benthic cover such as coral reefs caused by various sources of hazards [1].

Underwater images are, however, suffering from image quality due to the absorption and scattering of light [2]. Several methods have been proposed to enhance the quality of imagery recorded underwater [2] [3] [4] [5] [6]. Such improvements is an essentials step if more advanced applications of computer vision and photogrammetry, such as 3D reconstruction using stereo vision, are to be successful in aquatic applications. For instance Hogue *et al.* [7] developed a stereo vision-inertial sensing device to reconstruct complex 3D structures in both the aquatic and terrestrial domains.

Due to absorption and polarization of light as it reaches the seafloor, some pixels become brighter than others (shimmering) and colors degrade as light at longer wavelengths (green, red) is largely filtered in the first 4 meters of the water column [8]. Figure 1 schematically shows the main process of light interactions in the sallow seas.

While several studies aim to improve the SIFT image matching in other ways then by image enhancement [9] [10] [11] [12] [13], in this study we focus on the techniques for enhancing image quality of underwater recorded footage instead.

Based on Iqbal *et al.* [2], underwater image processing can be classified into two types: image restoration techniques and image enhancement methods. Image enhancement methods are quite simple than image restoration techniques. Image enhancement methods do not need a prior knowledge of the environment such as attenuation coefficients, scattering coefficients and depth estimation of the object in a scene.

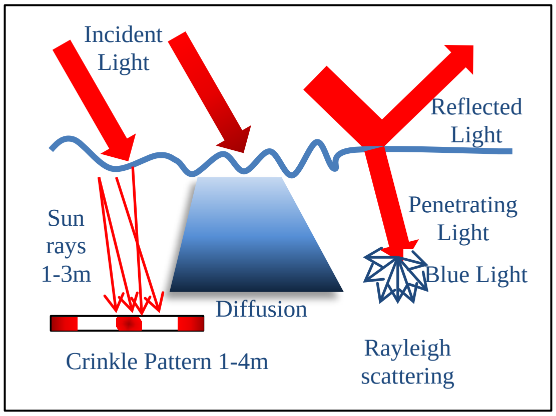

Figure 1: Water surface effects [8]

Several enhancement methods are used to enhance the quality of an image which includes gray scale manipulation, filtering and Histogram Equalization (HE) [14]. Histogram equalization is one of the popular technique for contrast enhancement because this method is simple and effective [14]. Contrast Limited Adaptive Histogram Equalization (CLAHE) has becoming successful histogram equalization method for low contrast image enhancement [15].

The performance of Contrast Limited Adaptive Histogram Equalization (CLAHE), contrast stretching, and histogram equalization method have been compared and analyzed by Singh *et al.* [5], which revealed that CLAHE method improved the contrast and equalizes the image histogram efficiently. Various histogram distribution which includes uniform, exponential, and Rayeigh distribution have been compared for film-based dental panoramic radiography [16]. Respectively, uniform, exponential, and Rayleigh distribution In their comparison, CLAHE with Rayleigh distribution produce more optimal quality than the other distribution.

In [2] authors Iqbal *et al.* proposed underwater image enhancement using an integrated color model. The model consists of contrast stretching Red Green Blue (RGB), transform RGB to Hue Saturation Intensity (HSI), saturation and intensity stretching of HSI. The result showed promising result.

Iqbal *et al* [6] also proposed an Unsupervised Color Correction Method (UCM) approach for underwater image enhancement. The proposed method efficiently removes the bluish color cast and improves the low red color, the low illumination and true colors of underwater images. The proposed method has produced better results compared to the existing method, namely Gray World, White Patch and Histogram Equalization. The other research that also concern to enhance the image quality could be seen at [17] [18] [19].

Several research to enhance the SIFT image matching also has been conduct, where the improvements are not in image enhancement area such as in [9] [10] [11] [12] [13].

Figure 2: Karimunjawa Island

Since the data collection is acquired from real underwater coral reef environment in rural area around Karimunajawa Island (see figure 2), the same constraints of underwater imaging such as the absorption and scattering of light discussed above are occurring that would hamper or degrade the SIFT-based image registration. Therefore, we proposed adaptive filtering base on Contrast Limited Adaptive Histogram Equalization (CLAHE) using Rayleigh scattering distribution for enhanced SIFT-based image registration.

2. METDHODS

This section details the methods and materials related to the presented research, notably the tested contrast stretching (CS), Contrast Limited Adaptive Histogram Equalization (CLAHE), and SIFT image matching methods and the imagery acquired of the coral reef.

2.1 Contrast Stretching

Contrast stretching (CS) is an image enhancement technique that attempts to enhance the contrast of an image by stretching the range of intensity values [20]. Contrast stretching of each pixel is computed by Eq. (1).

$$b[m,n]=\begin{cases}0; a[m,n]\le \min\\ (2^{B}-1).\dfrac{a[m,n]-\min}{\max-\min}; \min < a[m,n] < \max\\ (2^{B}-1); a[m,n]\ge \max\end{cases} \qquad (1)$$

where b is intensity value of enhanced image on coordinate $[m,n]$, a is original image, B is bit number, $\min$ and $\max$ are range contrast original image on percentile [21]. Changing local contrast is the shortcoming of the contrast stretching. This effect reduced detail an object on the image [16].

2.2 A Contrast Limited Adaptive Histogram Equalization

Contrast Limited Adaptive Histogram Equalization (CLAHE) is used to enhance the contrast of an image by transforming the value in the intensity image. CLAHE is the generalization of Adaptive Histogram Equalization (AHE).

CLAHE works by divide an image into several non-overlapping regions. Then for each region, histogram is calculated. Next, histogram is clipped by a desired limit for contrast expansion. The distribution of the pixel for the histogram can be transform into uniform, exponential, and Rayleigh distribution [16]. This paper focused on Rayleigh distribution, since it produce better image quality [16]. The gray level of Rayleigh distribution tends to be distributed more in the middle value of gray.

The clip limit β can be obtained by:

$$\beta=\frac{M}{N}\left(1+\frac{\alpha}{100}\left((S_{\max}-1)\right)\right) \qquad (2)$$

Where α is clip limit factor, M region size, N is grayscale value. The maximum clip limit is obtained for α =100.

2.3 SIFT Based Image Matching

Figure 3 shows the illustration of preprocessing step to SIFT image registration. CLAHE with Rayleigh scattering was proposed to improve the performance of SIFT. SIFT has been described in [22] which consist of four steps: scale-space extrema detection, keypoint localization, orientation assignment, and keypoint descriptor.

a) Scale-Space Extrema Detection

This step identifies all potential key point on all scales. Given the scale of an image space as a function of $L(x,y,\sigma)$, i.e the convolution between the Gaussian Kernel $G(x,y,\sigma)$ with the image $I(x,y)$ [22].

Operator difference of Gaussian (DOG) is used to find features on the imagery by compiling octave image pyramid with different scales.

$$D(x,y,\sigma)=(G(x,y,k\sigma)-G(x,y,\sigma))*I(x,y)$$
$$=L(x,y,k\sigma)-L(x,y,\sigma) \qquad (3)$$

b) Keypoint Localization

In this stage, stable keypoint will be selected from keypoint candidates. The emergence of feature-level stability is based on the features of each octave.

c) Orientation Assignment

Orientation of the keypoint based on local gradient direction of each image, thus making the descriptor invariant to rotation.

d) Keypoint Descriptor

Local gradient image is computed at each scale region around the keypoint. These are transformed into representation that allows the distortions and illumination changes of shape.

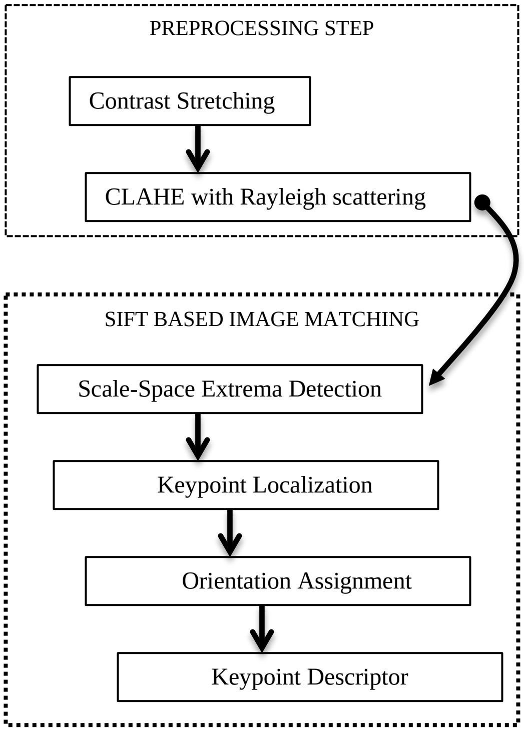

Figure 3: Illustration of Preprocessing step to SIFT image registration.

Wang *et al.* [23] stated that DOG is not stable for underwater image corner detection caused by the noise and abominable light conditions. In order to address this problem, the preprocessing quality of the image could be a solution to the performance of image matching [23].

3. MATERIALS

The coral reef surveyed as a use case for this study is located in Karimunjawa Island Central Java. Karimunjawa is a National Marine Park declared as a Natural Conservation Area by Decree of the Minister of Forestry, located at 5°49'-5°57' South Latitude and 110°04'-110°40' East Longitude in the Java Sea, north of Java, Indonesia [24]. The high level of biodiversity represents the ecosystem of northern coast of Central Java, Indonesia.

Figure 4: Karimunjava's Coral Reefs

Indonesia is a country that is part of the Coral Reefs Triangle owned total ranging from 18% of coral reefs around the world [1], but it is becoming a major concern in the world, since only 5.23% of coral reefs in Indonesia are still in a good conditions [25]. This condition puts Indonesia as the country with the status of coral reefs are most threatened according to the reef at risk.

A pair camera Olympus Tough-8010 cameras and resolution of 1280 x 720 pixels were used to obtain the scene (see figure 5). The acquisition of our data is shown in figure 6.

Figure 5: Low Cost Multi-View Camera Installation

Figure 6: Data Acquisition

30 image-pair from the dataset was selected to test our image enhancement framework. Keypoints and feature matching produced by SIFT were extracted from each of the image-pair to measure the performance of image enhancement. Three conditions were observed by SIFT performance: SIFT matching without image enhancement, SIFT matching using contrast stretching, and SIFT matching using CLAHE with Rayleigh distribution. Adobe Photoshop was utilized to implement contrast stretching with the value of contrast is -50, -25, 0, 25, 50, 75, and 100.

4. RESULTS AND DISCUSSION

This section assesses the results of the two image enhancements methods by comparing their relative impact on the success of the SIFT image matching. Figure 7 shows the number of keypoints obtained from the camera. The number of keypoints were produced by CLAHE-Rayleigh distribution is higher than contrast stretching at the whole image-pair. Figure 8 shows that enhancement using CLAHE-Rayleigh distribution improved the number of matching points. Detailed image matching of image-pair showed in table 1.

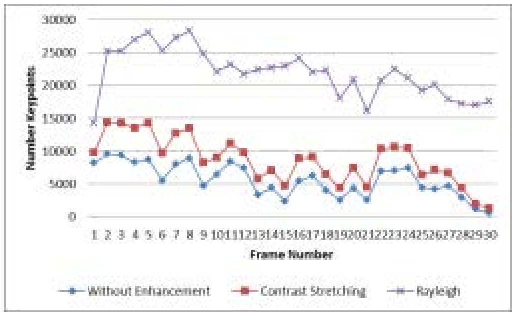

Figure 7: Number of keypoints in camera by without, contrast stretching and CLAHE enhancement

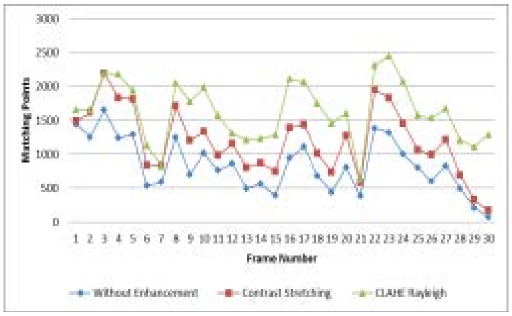

Figure 8: Number of matching points by without, contrast stretching and CLAHE enhancement

Table 1: Number of matching points of each image-pair, mean, standard deviation, confident interval, and range for the true population mean (lower and upper limit) by without, contrast stretching and CLAHE

Image-Pair	Without Enhancement	Contrast Stretching	CLAHE Rayleigh
1	1452	1494	1656
2	1249	1620	1650
3	1656	2192	2204
4	1244	1833	2182
5	1294	1817	1937
6	535	835	1129
7	593	839	822
8	1251	1710	2050
9	704	1200	1779
10	1022	1344	1986
11	763	982	1572
12	866	1155	1312
13	496	803	1211
14	565	873	1233
15	389	749	1283
16	944	1395	2116
17	1108	1436	2068
18	688	1010	1752
19	441	743	1460
20	816	1279	1607
21	380	587	631
22	1388	1954	2311
23	1326	1835	2452
24	999	1462	2073
25	804	1071	1573
26	606	990	1538
27	834	1216	1679
28	497	697	1204
29	215	329	1107
30	76	173	1288
mean ($\bar{X}$)	840.03	1187.43	1628.83
Standard Deviation	395.78	490.39	451.39
Confident Interval	±141.63	±175.48	±161.52
Lower Limit	698.4	1011.95	1467.31
Upper Limit	981.66	1362.91	1790.35

Based on table 1, two sample t-test was used to test the significant difference in terms of image matching number in contrast stretching and CLAHE Rayleigh enhancement. Table 2 shows that p-value for contrast stretching is 0.0038 and t-value for CLAHE Rayleigh is 1.37E-09 which is smaller than 0.05, therefore the outcome reject null hypothesis at 5% level of significant. Two-sample t-test has proven that both contrast stretching and CLAHE Rayleigh enhance the SIFT image matching. The significant result is achieved by using CLAHE Rayleigh.

Table 3 shows that *F*-value for contrast stretching is 9.117 and *F*-value for CLAHE Rayleigh is 51.79 which are higher than *F crit*, therefore the outcome also reject null hypothesis at 5% level of significant.

Table 2: Two-sample t-test

	t	df	sd	p
Mean of Without Enhancement **Mean of Contrast Stretching**	-3.0195	58	445.5985	0.0038
Mean of Without Enhancement **Mean of CLAHE Rayleigh**	-7.1968	58	424.4952	1.37E-09
Mean of Contrast Stretching **Mean of CLAHE Rayleigh**	-9.114	58	442.3956	0.000687

Table 3: Analysis of Variance

Source	SS	df	MS	F	Prob> F
Between groups	9.38e+06	2	4.69e+06	23.41	7.34e-09
Within groups	1.74e+07	87	2.00e+05		
Total	2.68e+07	89			

Table 4 shows that contrast stretching and CLAHE-Rayleigh are significant for enhancement at 5% level of significant. Using the sample mean of matching points, the improvement of SIFT using contrast stretching and CLAHE with Rayleigh distribution achieved 37% and 78% respectively. The number of matching points available to the SIFT-based image registration improved by 41% (from 37% to 78%) using the proposed CLAHE-Rayleigh distribution image enhancement method with confident interval ±161.52 and confident level 95%. Hence, we conclude that CLAHE is better than contrast stretching. The improvement rate is calculated using Eq. 4:

$$improveRate(\%) = \frac{\overline{X_b} - \overline{X_a}}{\overline{X_a}} \qquad (4)$$

Where $\overline{X_a}$ is sample mean of image matching without enhancement and $\overline{X_b}$ is sample mean of image matching with enhancement.

Table 4: Post-Hoc Test

Tukey's HSD Test			
$\alpha = 0.05$			
Conditions	Mean Square	p	Significant
Without Enhancement *vs.* Contrast Stretching	1857662.069	0.003291	Yes
Without Enhancement *vs.* CLAHE	9489165.517	1.25402E-09	Yes
Contrast Stretching *vs.* CLAHE	2949765.517	0.00068693	Yes

The comparison of image quality before and after enhancement is shown in figure 9. For briefness, in this paper we present only three images of the dataset to exemplify the results of the new method.

5. CONCLUSSIONS AND FUTURE WORKS

This research explained the preprocessing step of underwater image registration using image enhancement framework. This paper proposed a method for image enhancement using adaptive filtering base on CLAHE using Rayleigh Distribution. Results showed that after applying the CLAHE with Rayleigh distribution registration success of SIFT increased by 41% compared to the reference method (a straightforward contrast stretching enhancement). From the ANOVA results follows that the null hypothesis can be rejected and concluded that there is a significant difference among SIFT without enhancement, SIFT with contrast stretching and SIFT with CLAHE-Rayleigh at 5% level of significance (ANOVA, F=23.41, df=2, p-value=7.34e-09). The above finding concludes that CLAHE-Rayleigh is better compared to contrast stretching.

The adaptive adjustment of CLAHE could be a solution to improve the performance of image matching compare to manual adjustment of contrast stretching that is very time consuming. As a follow-up study, CLAHE-Rayleigh should be compared with other image enhancement techniques (or a combination of techniques 'hybrids') to assess their relative impact on the success of SIFT-based image matching of underwater photography.

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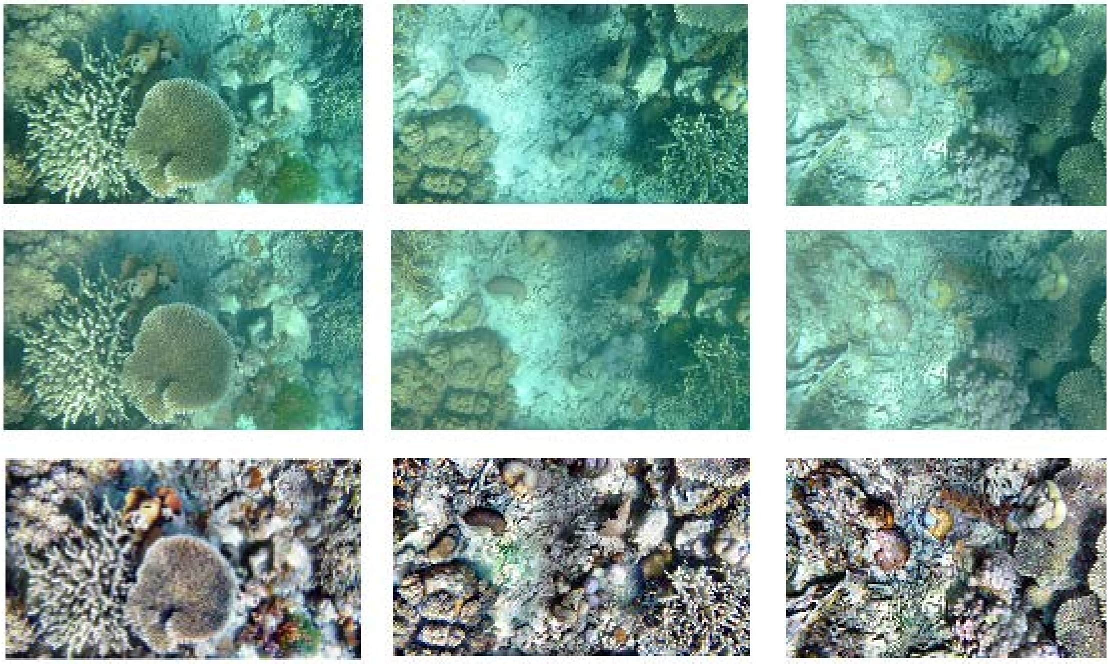

Figure 9: Comparison of image quality before and after enhancement. ***First Row.*** *Without image enhancement.* ***Second Row.*** *Image enhancement using contrast stretching.* ***Third Row.*** *Image enhancement using CLAHE with Rayleigh distribution.*