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***Abstract*—Most diatom images scanned from digital microscopes suffer from low contrast, noise, and contain unwanted floating particles and debris in a single image. Moreover, the active movement of diatom along with poor lens focusing produces a blurred image. Thus, in this paper, we introduce a new integrated automatic background removal technique (IABR) to enhance low-quality microscopic diatom images. This paper describes a two-step process of microscopic diatom image for image smoothing. First, haze removal technique is applied to the low light image to enhance and removes the image from haze and noise. Second, the background removal technique extracts the diatom cell from the background image and improves the image contrast. The output results show that the proposed IABR method has successfully enhanced and smooths low-quality diatom images by removing the image background and improving image contrast.**

Keywords—diatom, integrated automatic background removal, image enhancement, image smoothing

I. INTRODUCTION

Diatom is a large and diversified group of simple, typically autotrophic creatures ranging from single cells to multicellular animals [1]. Diatom alters water qualities such as color, odor, taste, and chemical composition, thereby posing health risks to humans and animals. It size is too small and only be observed through microscope [2].

Microscopy images are produced by a microscope and easily transferred into digital form for storage, analysis, or processing before being displayed and interpreted [3]. A microscope camera took images that are usually contained noises, stains, and uninteresting background. Multiple objects may become entangled in certain photos, and they are frequently contaminated with other microorganism, dust, specks, and debris [4][5]. Using a digital microscope to observe live diatoms is difficult, especially if the diatom cells are motile. Furthermore, the active motion of diatom, along with poor lens focusing will produce a blurred image [6][7].

Image enhancement improves the appearance of a captured image by removing various types of noise to improve contrast or visualization of image features and consequences, allows for accurate image analysis [8]. To improve the microscopic diatom images with background removal, a new method called automatic background removal is introduced. It leaves only the diatom cell as the resultant image in order to assist user-oriented or automated operations such as object analysis, identification, recognition and segmentation.

This paper describes a two-step process for improving diatom images from microscopic images. The haze removal technique is applied to first enhance the image quality by removing haze and noise from the image. It reduces noise to improve image intelligibility and appearance. The background is then removed using an edge mask crop to extract the diatom cell.

The rest of the paper is structured as follows. Section 2 shows the work that has already been done in similar areas of image enhancement. In Section 3, the proposed method is described in detail. Section 4 tells about the experiments' results and the discussions. Section 5 then elaborates on the study's results.

II. PREVIOUS WORK

Reza [9] proposed contrast-limited adaptive histogram equalization (CLAHE). An image is divided up into block tiles and contrasts using the CLAHE expansion method of the AHE algorithm, which ultimately results in less noise. CLAHE also effectively limits noise amplification, but the enhancement effect around the edges is poor. Therefore, the CLAHE method is frequently chosen in offline applications due to its high computational cost.

Ooi et al. [6] introduced toboggan contrast enhancement (TCE) for improving hazy microscopic images. The Gaussian filter is utilised to decrease the amount of haze within an image. TCE is used to restore the edges because the Gaussian filter causes the edges of the image's objects to become blurrier. The contrast and noise level of microscopic images are improved with this method.

Flow et al. [10] introduced a multi-technology fusion low-contrast microscopic image enhancing technique (MTF). High and low frequency picture components are separated to reduce noise. Next, Sobel, Laplacian and Gaussians (LoG) operators were combined with contrast limited adaptive histogram equalisation to enhance low-contrast microscopic image quality.

Abdul Ghani and Ab. Nasir [11] introduced integrated dehazed image fusion to improve underwater object visibility (IDF). The input image is changed homomorphically to improve background-to-foreground luminosity. The dehazing process uses an integrated contrast-increasing mechanism and dual image fusion. Finally, local histogram augmentation improves the image's local contrast.

Chong et al. [12] proposed a dual image fusion technique to reduce the non-uniform illumination for underwater image. To minimize dehazing image, the Homomorphic filtering process and histogram matching is applied. Next, dual image global stretching with local stretching as post-processing to increase color channel of the image, then to enhance the final image, sharpening process is applied. The resultant image shows that this method improved the image's contrast, color and details. On the other hand, Serdar Cakir et al. [13] proposed contrast enhancement of microscope images using image phase information (PCM). The proposed method converts image phase changes into magnitude variations to improve structural features and visibility. The output images are better than several previous CLAHE methods.

The following section discusses the image dataset and proposed method in detail.

III. Methodology

A. Image Dataset

Diatom samples were taken from the Kuala Pahang Jetty during high tide at 15 parts per thousand (ppt) salinity using a 20µm plankton net. The diatom samples were then analyzed using Nikon Eclipse Ni optical microscope at low (100×), medium (200×), and high magnification (400×). The microscope stage is then moved to find diatom in water samples through the lens. These images are transferred to Nikon NIS Elements Imaging Software over a USB connection with a Nikon DS-Ri1 camera and the captured images were digitized in RGB format. The original resolution of diatom image was 1280x1024 pixels.

In order to strengthen the robustness of the classifier, photos taken in the same field of vision but with varying focus lengths and lighting intensities are collected. These images capture a variety of circumstances and viewpoints. Finally, for each diatom species, approximately 100 images are gathered.

B. Integrated Automatic Background Removal (IABR)

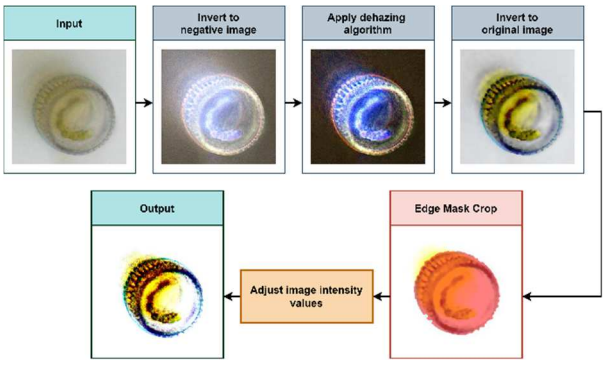


Fig. 1. The proposed IABR method's flowchart

The proposed IABR method is illustrated in the flowchart presented in Figure 1. The IABR method involves two primary steps that result in only a diatom cell as the final output result. The steps begin with applying the haze removal technique to minimize the noise in the image. After that, the diatom cell is extracted from the background image using the background removal technique.

The haze removal technique used on low-light images with noise and haze consists of three basic steps. The original image of *Cyclotella,* as shown in Figure 2(a), is first inverted into a negative image to generate and increase hazy-appearing low-light image regions as described in Equation (1) [14].

$$R^c(x) = 255 - I^c(x) \quad (1)$$

where $R^c(x)$ is the inverted intensity image R and c is the RGB color channel. $I^c(x)$ is the color channel intensity of pixel x for a specific low-light input image I. Figure 2(b) shows the inverted low light of the *Cyclotella* image. The enhanced haze removal technique's next step is applying the dehazing algorithm to the inverted low-light image, as shown in Equation (2) [15].

$$R(x) = J(x) \times t(x) + L(1 - t(x)) \quad (2)$$

where $R(x)$ is the brightness of the microscope camera's pixel x. $J(x)$ indicate the scene's intensity. A represents the global total amount of light emitted by the atmosphere and $t(x)$ shows the microscope camera's light capture percentage. The result of haze removal is demonstrated in Figure 2(c).

The inversion into a negative image shown in Equation (1) is replicated to get an enhanced output image. As a result, the applied steps lower noise and haze to a certain degree and generally improves image quality as shown in Figure 2(d), and a better diatom image is produced.

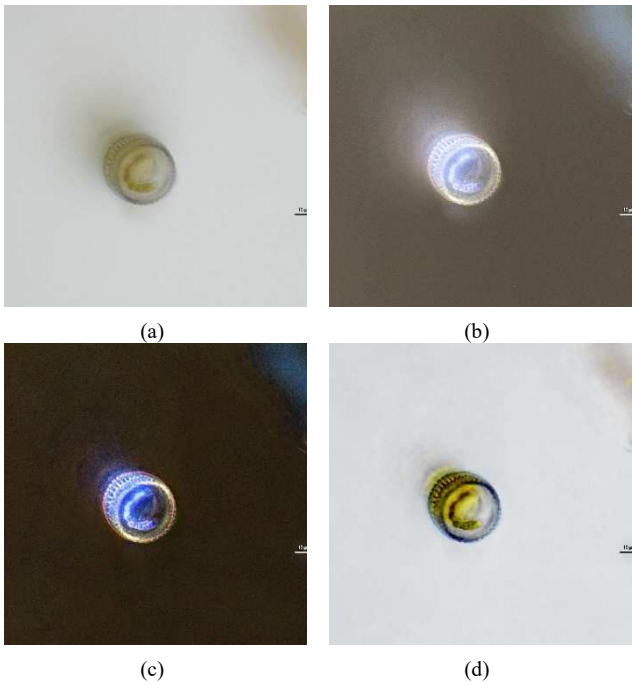


Fig. 2. (a) Original image of *Cyclotella* (b) Negative image (c) Dehazing algorithm (d) Output image after the noise and haze removal.

The output image from the haze removal technique is used with an automated labelling of the area of interest (ROI), which is the diatom cell, for the background removal procedure. Before the diatom is automatically cropped, the

TABLE I. QUANTITATIVE EVALUATION OF THE DIFFERENT METHODS FOR THE PHYTOPLANKTON DIATOM IMAGE IN FIGURES 5 TO 7.

Figure	Method	Qualitative Performance Measures				
		Entropy	Average gradient	PSNR	UIQI	EBCM
Pleurosigma	CLAHE	5.988	4.368	**21.383**	**0.401**	9.115
	TCE	6.409	**5.685**	7.150	0.218	81.885
	MTF	5.966	4.123	5.414	0.256	82.005
	PCM	**6.830**	5.585	18.469	0.222	23.351
	IABR	0.390	1.332	3.831	0.033	**84.197**
Thalassionema	CLAHE	5.667	5.335	**25.990**	**0.357**	8.172
	TCE	6.530	**11.298**	8.585	0.177	81.348
	MTF	**7.184**	4.625	10.186	0.118	46.819
	PCM	6.616	7.491	21.041	0.194	30.767
	IABR	0.423	2.991	4.483	0.031	**83.997**
Rhizosolenia	CLAHE	5.672	6.514	**22.691**	**0.353**	4.876
	TCE	6.610	**9.571**	7.861	0.152	80.746
	MTF	**7.135**	5.267	8.216	0.110	55.603
	PCM	6.614	4.326	19.688	0.192	23.041
	IABR	0.646	2.195	3.813	0.035	**84.102**

[a.] The value in bold represents the best result from the comparison.

ROI edge will be identified and marked. After extracting the diatom cell, the background areas of the image will be transformed into a white area.

Background removal uses morphological operators to minimize dark regions, producing in a bright output image. The erosion process dulls the image's dazzling details [16]. The morphological procedure is to differentiate the diatom cell's ROI from the background. Equation (3) represent the binary dilation.

$$A \oplus E = \{z | (\hat{E})_z \cap A \neq \emptyset\} \quad (3)$$

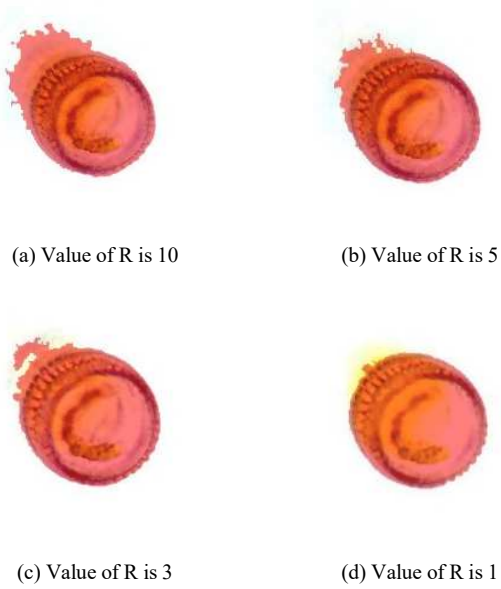
where $\hat{E}$ denotes the structural element of E reflection. In other words, it is the collection of pixel positions z in which the reflected structuring element overlaps with the foreground pixels in A when translated to z [17].

For the binary erosion of A by E, labeled $A \ominus E$ is determined by Equation (4).

$$A \ominus E = \{z | E_z \subseteq A\} \quad (4)$$

where z is the set of pixel locations in which the structuring element translated to location only overlaps with foreground pixels in A.

Morphological dilation and erosion require a flat structural element [18]. It produces a shape-based structural element to highlight ROI. The function's shape is 'disc'. A positive R parameter defines a flat, disk-shaped image element. Aiman Syahmi et al. [19] found that R's optimal value is 1, which is the lowest parameter value. Figure 3 shows the dilation and erosion function analysis sample result for optimum R-value. Foreign particles are unmarked when R equals 1.



(a) Value of R is 10 (b) Value of R is 5

(c) Value of R is 3 (d) Value of R is 1

Fig. 3. Resulted image of dilation

After background removal, mask cropping eliminates the background regions, and only the ROI remains in the final image. The cropping method removes all red highlights from a binary image and returns a single diatom cell (refer to Figure 4). Figure 4(a) shows highlighted diatom images. Figure 4(b) shows diatom after mask cropping, which produces a single cell image.

(a) Mask cropping (b) After mask cropping process

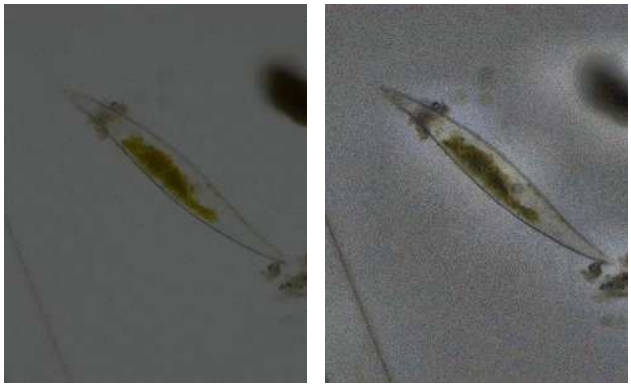
Fig. 4. Highlighted diatom cell before and after edge cropping

The final step is to apply an enhanced contrast adjustment by altering the image contrast. The contrast of the diatom cell image was modified based on the assumption that 1% of the dynamic range values are saturated at low and high intensities, respectively. Figures 5 through 7 illustrate that the proposed IABR method improves overall image contrast.

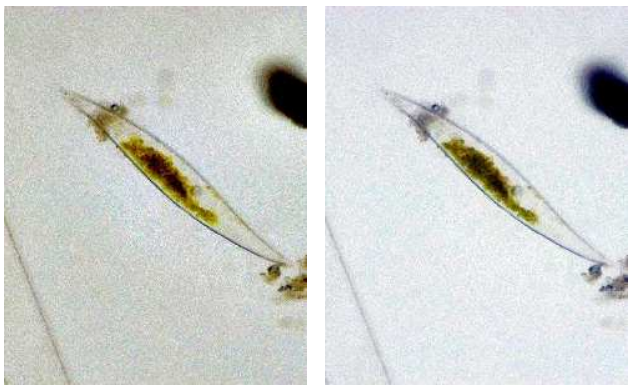
IV. Result and Disscussion

The developed algorithm presented in the previous section was implemented in MATLAB R2021a. It takes around 10 seconds to enhance a single image with a resolution of 1280x1024 pixels. The resultant image of the proposed method is compared with other methods that are CLAHE, TCE, MTF and PCM on the microscopic image sets. Evaluations on both a qualitative and quantitative level are carried out to guarantee that the proposed IABR method can preserve the diatom's original form and finer details compared to other methods. As shown in Figures 5 through 7, the resulting image demonstrates that the proposed IABR method successfully sharpened the diatom's edge compared to the original image and other methods.

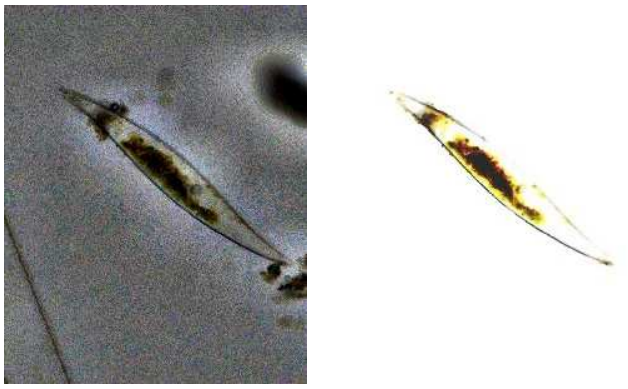
Entropy, average gradient, Universal Image Quality Index (UIQI), Peak signal-to-noise ratio (PSNR), and edge-based contrast measure (EBCM) are computed as quantitative evaluation parameters to evaluate the enhancement performance of the diatom output image objectively, as shown in Table 1. In addition, the proposed method improves the contrast of the diatom cell, making the diatom structure smoother and more amenable to processing in subsequent phases such as segmentation or identification.



(a) Original image (b) CLAHE

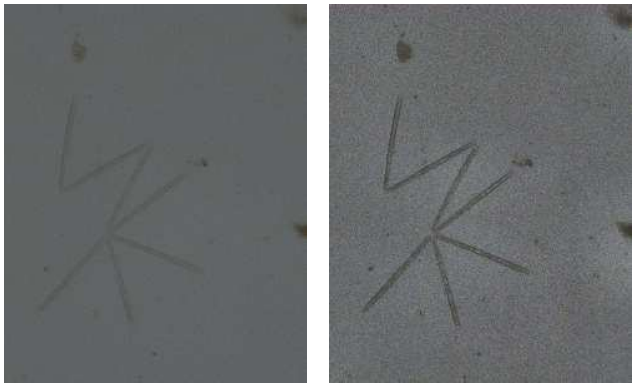


(c) TCE (d) MTF

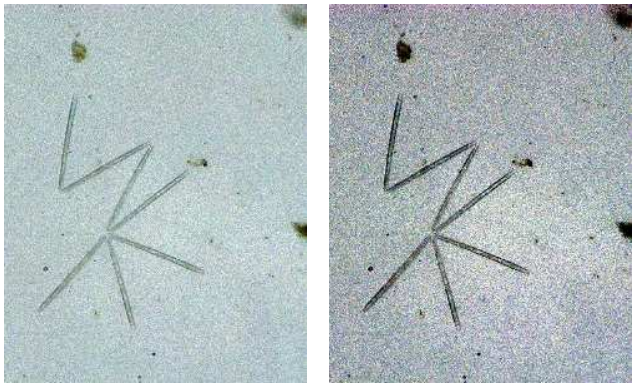


(e) PCM (f) IABR

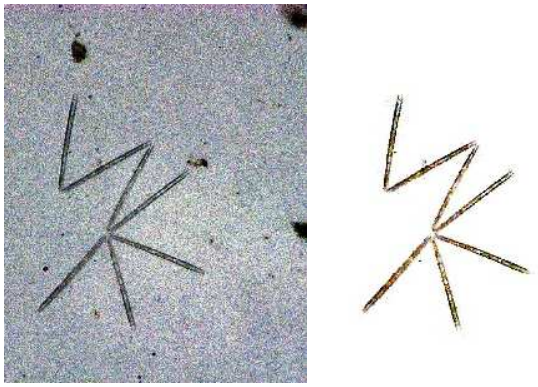
Fig. 5. (a) Original image of *Pleurosigma*, (b) CLAHE, (c) TCE, (d) MTF, (e) PCM, (f) the proposed IABR method.



(a) Original image (b) CLAHE

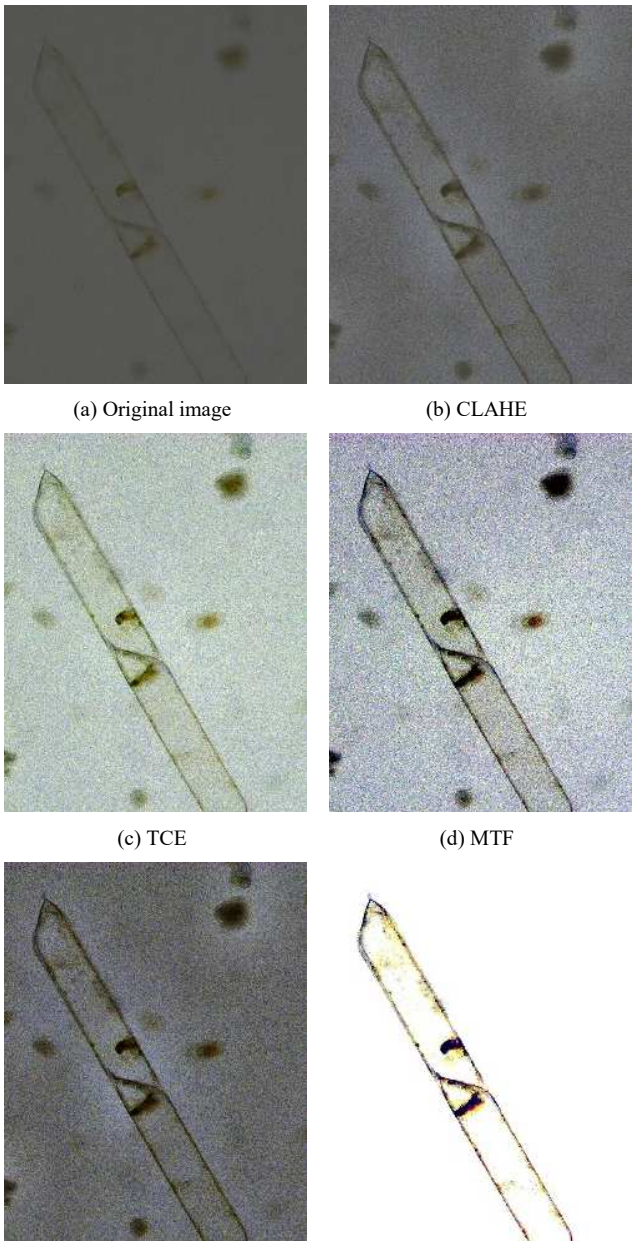


(c) TCE (d) MTF



(e) PCM (f) IABR

Fig. 6. (a) Original image of *Thalassionema*, (b) CLAHE, (c) TCE, (d) MTF, (e) PCM, (f) the proposed IABR method.



(a) Original image (b) CLAHE

(c) TCE (d) MTF

(e) PCM (f) IABR

Fig. 7. (a) Original image of *Rhizosolenia*, (b) CLAHE, (c) TCE, (d) MTF, (e) PCM, (f) the proposed IABR method.

V. Conclusion

Microscopic diatom images include edge blur and a lack of detail, reducing image quality and visual effect. The proposed integrated automatic background removal (IABR) method consists of two steps: haze removal technique and background removal successfully enhance the microscopic diatom image quality, in contrast, edge, color, and cell details. After implementing the haze removal technique, the first step to remove the noise and haze effectively enhanced the overall microscopic diatom image. The second step is applied to extract the diatom cell from the image background and retains only a single diatom cell in the final output image. Experimental results demonstrate that the proposed IABR method is more effective to other microscopic diatom image enhancement techniques and can be utilised to lay the groundwork for microscopic image analysis and classification.

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