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Improving the Quality of X-Ray Images of the Lungs of COVID-19 and Healthy Patients Using the Contrast Limited Adaptive Histogram Equalization (CLAHE) Method in Batam

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Abstract

X-ray imaging is a widely used technique for observing lung patients conditions. Compared to other radiographic methods, X-ray is more accessible, cost-effective, and commonly available in healthcare facilities. However, digital X-ray images often suffer from low quality, particularly in terms of image contrast, which complicates the process of identifying lung abnormalities accurately. In Embung Fatimah Hospital in Batam, X-ray imaging is routinely used to screen COVID-19 and healthy patients. To address the issue of poor image contrast, this study applies the Contrast Limited Adaptive Histogram Equalization (CLAHE) technique, aiming to enhance image clarity and support more effective analysis. The research involved 20 lung X-ray images, consisting of 10 from COVID-19 and 10 from healthy patients, retrieved from the hospital's radiology department system. The images underwent digital processing using Matlab software. The workflow included converting the images to grayscale before applying contrast enhancement with the CLAHE method, using three different distribution types: Uniform, Rayleigh, and Exponential. Following enhancement, Peak Signal to Noise Ratio and Mean Square Error metrics were calculated for each distribution type to evaluate image quality improvement. The result shown that all three CLAHE methods effectively enhanced the visual contrast of the lung images. The average MSE values for COVID-19 images were 26.27, 25.25, and 25.62, while for healthy images they were 28.27, 27.35, and 27.44. Meanwhile, the average PSNR values for COVID-19 images reached 155.63, 196.58, and 180.58, with healthy images scoring 98.27, 122.22, and 118.97. Overall, the process achieved an accuracy of 100%.

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1. Introduction

Nowadays, in this era of computerization and digital, documenting the results of tasks and work uses photos or drawings [1]. Photos produced in the form of digital images require processing known as image processing [2]. Image processing, which is a branch of informatics (computer science), is not only used in the world of photography, but in various aspects of scientific disciplines that have relevance, such as the world of radiography or medical images [3]. Radiographic images such as X-ray X-rays, MRI, CT-Scans and so on can be processed using image processing [4]. Since December 2019, when the Coronavirus disease 2019 or COVID-19 emerged in the city of Wuhan and spread rapidly throughout China, data was needed on the clinical characteristics of affected patients [5]. COVID-19 is a disease that attacks the lungs and respiratory system, so X-Ray images can be used to detect COVID-19 disease [6]. X-Ray image results in COVID-19 sufferers showed that fluid in the lungs would look like white spots. The buildup of this fluid in the chest cavity can interfere with the performance of the lungs, causing the sufferer to experience difficulty breathing, and at its worst, this condition can even cause death, so treatment must be carried out immediately to prevent an increase in patients due to this pandemic [7]. Radiography is helpful for the assessment and follow-up of COVID-19 disease providing physicians with accurate insight into disease progression [8].

Medical imaging plays an important role in supporting clinical decision making in the diagnosis, management, and treatment of COVID-19 patients [9]. The condition of the patient's lungs is carried out by medical personnel using X-Ray photos, but the quality of the X-Ray images is sometimes poor or not optimal [10]. Research to identify the use of transfer learning architecture in detecting COVID-19 from Computerized Tomography scans of the lungs. This study evaluates the transfer learning-based framework as an alternative to contemporary methods used to detect the presence of the virus in patients. The highest performing model, VGG-19 implemented with CLAHE, on the SARS-COV-2 dataset, achieved an accuracy and recall of 95.75% and 97.13%, respectively. Improving the quality of x-ray images is needed to help doctors or health practitioners see lung x-ray results more clearly [11]. One method used to improve image quality is Contrast Limited Adaptive Histogram Equalization (CLAHE) [12][13][14]. The comparative analysis research of MSE and PSNR values for X-Ray COVID-19, Pneumonia and Normal using two methods CLAHE and HE can be concluded that the CLAHE method is able to provide clearer images on X-Ray COVID-19, X-Ray Pneumonia and Normal X-Ray images compared to the HE method. In practice, the CLAHE algorithm distributes image brightness and limits noise magnification [15]. CLAHE is very popular for local contrast enhancement which has proven to be robust and useful for several applications [16].

Research increases the contrast of radiographic images using Contrast Limited Adaptive Histogram Equalization (CLAHE). This system is proposed to improve lung x-ray images which are always unclear. In medical imaging, accurate diagnosis relies heavily on effective image enhancement techniques, especially for X-ray images. Existing methods often suffer from challenges such as sacrificing global image characteristics over local image characteristics or vice versa. This method is called G-CLAHE (Global-Contrast Limited Adaptive Histogram Equalization), which is very suitable for medical imaging focusing on X-ray. G-CLAHE is adopted from Global Histogram Equalization (GHE) and Contrast Limited Adaptive Histogram Equalization (CLAHE) to take both advantages and avoid the disadvantages to preserve both local and global characteristics. Experimental results show that this method can significantly improve current algorithms to effectively overcome their limitations and enhance the contrast and quality of X-ray images for diagnostic accuracy [17]. CLAHE method for improving the quality of X-ray images through the application of CLAHE in a sequential manner, using two distinct color spaces and varying parameters for each step. The findings indicate that this approach results in enhanced visual quality and greater accuracy in detecting specific features compared to conventional methods. This would involve presenting the enhanced images to these professionals and soliciting their opinions on the improvements in image quality and the ability to accurately diagnose medical conditions. The combination of subjective evaluation and objective measurements of image quality will provide a comprehensive assessment of the proposed image enhancement technique [18]. The Contrast Limited Adaptive Histogram Equalization (CLAHE) technique produces very satisfactory values. The CLAHE technique provides more details with high contrast by using Matlab 2015a as the image processor [18].

Embung Fatimah Hospital in Batam uses an X-ray machine to examine the thorax of COVID-19 patients. During the pandemic, many patients checked themselves for chest X-rays. This hospital is the only referral health facility for the people of Batam City. However, poor image quality is an obstacle so that its quality needs to be improved. Optimal image quality makes it easier for doctors to help doctors improve the accuracy of detecting COVID-19 disease in the lungs. The CLAHE method is used to contribute to the branch of image processing science for image processing such as medical images. CLAHE is needed to improve the quality of poor chest X-Ray images of COVID-19 patients and healthy patients. The data used were 10 X-Ray images of the lungs (thorax) of COVID-19 patients and 10 healthy patients obtained from Embung Fatimah Hospital, Batam City, which is one of the COVID-19 referral public hospitals and Medical Checkups in Batam City [16]. During the COVID-19 pandemic, patients infected with the COVID-19 virus who were referred to Embung Fatimah Regional Hospital underwent lung x-rays. Because the price is relatively cheap, X-Ray images are used in hospitals as a means of visually detecting COVID-19.

These medical devices are relatively affordable, easy to use and low cost compared to medical equipment that has similar functions. Embung Fatimah Hospital, Batam City, only uses X-Ray equipment to examine the lungs of patients suffering from COVID-19 and healthy patients for medical check-up purposes.

In this study, X-ray data obtained from the X-RAY machine of Embung Fatimah Hospital in DICOM format was exported to JPEG/JPG format via the MicroDicom application which is an application for viewing X-ray, USG, and MRI results along with patient information, and can also be exported to other formats such as TIF, BMP, and so on. The file was exported to JPEG/JPG format with a size of 1024 x 2048 pixels and cropped. After that, the data was processed using the Matlab 2015 application with the CLAHE method by looking at the MSE and PSNR values. This process is carried out from the image acquisition stage, then changing the grayscale format and then using the CLAHE method such as uniform, rayleigh and exponential. It is hoped that this study can help medical personnel in viewing X-ray results clearly to treat and diagnose patients.

2. Research Methodology

2.1 Research Flowchart

The research stages were created to make it easier for writers to carry out research so that it is easier to understand and does not stray from the main topic of discussion. The steps taken in the research framework are arranged systematically to solve existing problems. The stages of research carried out can be shown in Figure 1.

The stages of research carried out include:

1. Identifying Lung Image Problems,
   Embung Fatimah Batam Hospital only has an X-ray to check the thorax and lungs. However, the quality of the X-ray image is not visually good. This becomes an obstacle when detecting disease so the quality needs to be improved
2. Analyzing Lung Image Problems,
   The image contrast quality is not good due to the lack of contrast in the X-ray image results. Therefore, a method is needed to correct this deficiency, namely CLAHE.
3. Determining Research Objectives,
   The research objectives to be realized are: contributing to the branch of image processing science for image processing such as medical images, improving the quality of x-ray lung images of COVID-19 and healthy patients using the Contrast Limited Adaptive Histogram Equalization (CLAHE) method.
4. Studying the Literature about CLAHE,
   Researchers studied literature, articles from quality and accredited journals which were used as references.
5. Collecting Data and Information on Research Objects,
6. Analyzing and Planning CLAHE Applications,
   Analyzing application requirements and designing applications. The application is used to help identify images of the lungs (thorax) of COVID-19 patients and healthy patients using the CLAHE method. The application was created with the support of Matlab R2015a software.
7. Identification of lung images with CLAHE,
   Medical images are processed to produce new images with different qualities. This stage carries out image checking steps using the CLAHE method with an application that has been created with the help of Matlab software. The input image is a file with the Bitmap extension (.*bmp). DICOM format is exported in BMP form via the MicroDicom application. The image that is read and displayed in the form of a Bitmap file is then converted into a form *grayscale*(grayish image)[20]. The goal of changing to *grayscale* is to simplify the image model because color images consist of a 3 layer matrix, namely R-layer, G-layer and B-layer [17].
8. Testing CLAHE Image Results
   Testing was carried out using PSNR and MSE
9. Results and Discussion CLAHE Image
   Identification results if PSNR results after processing *image* if the CLAHE method shows a value above 30 dB, the image quality is said to be good and the CLAHE method is effective in increasing image contrast[21]. Furthermore, if the resulting MSE value is lower and closer to 0 (zero), it will be more similar to the original image and the quality of the image will be good and it can be concluded that CLAHE has succeeded in improving the quality of the Lung X-Ray image.[22].

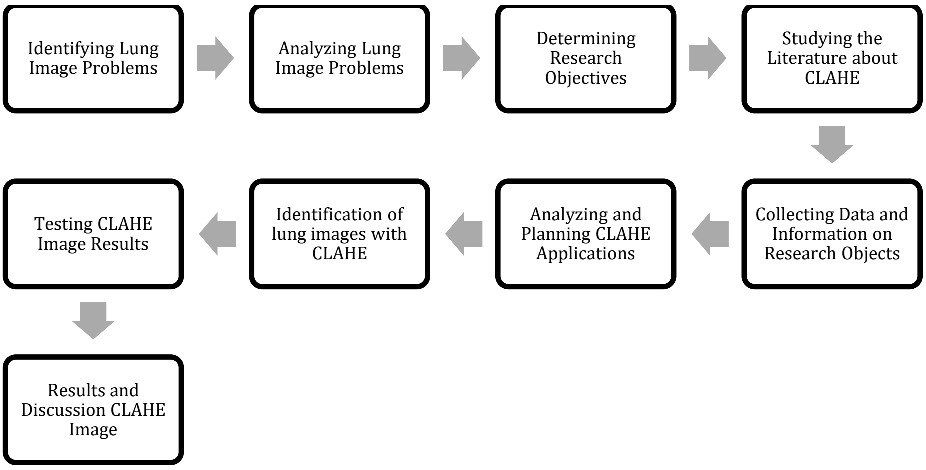


Figure 1. Research Framework

2.2 Metode

The CLAHE (Contrast Limited Adaptive Histogram Equalization) research method is usually used in the field of digital image processing, especially to increase image contrast. CLAHE is a development of the AHE (Adaptive Histogram Equalization) method, but with improvements to overcome excessive noise that often appears in AHE. The image that is read and displayed in the form of a Bitmap file is then converted into a form *grayscale*(grayish image)[20]. The goal of changing to *grayscale* is to simplify the image model because color images consist of a 3 layer matrix, namely R-layer, G-layer and B-layer [17]. The formula for changing an image into a shape *grayscale*(grayish) is presented in Formula 1.

$$I = 0{,}2989\, M + 0{,}5870\, H + 0{,}1141\, B \quad (1)$$

Where M is the red scale value, H is the green scale value, and B is the blue scale value [22]. The Matlab formula has been converted into standard syntax, namely *syntax rgb2gray*. *Syntax* This automatically changes the image to grayscale with parameter values according to formula 1[23]. The stages of the CLAHE method in research can be seen in the image Figure 3.

Next, calculate CLAHE using formula 2. Where β is the CLAHE result, *p* is the number of pixels in each block, *q* is the dynamic range in this block, S_{max} is the maximum slope, and α is the clip factor [24].

$$b = \frac{p}{q}\left(1 + \frac{\alpha}{100} S_{max}\right) \quad (2)$$

CLAHE using the syntax in Matlab, namely *adapthisteq* with parameters *clipLimit* which has been determined.Limitation *cliplimit* used is 0.02. J=*adapthisteq* (I,*'clipLimit',valueClipLimit,'Distribution','type distribution* ');

where J is the CLAHE image, I is the image *grayscale, ClipLimit* is a contrast factor that prevents excessive image saturation, especially in homogeneous areas, *valueClipLimit* is value *clip limit* (the default value is 0.01), *Distribution* is the desired histogram shape, *type distribution* is a type of type *histogram(Uniform, Rayleigh, Exponential)Hasil syntax grayscale* and CLAHE is interpreted inward *pseudocode* 1.

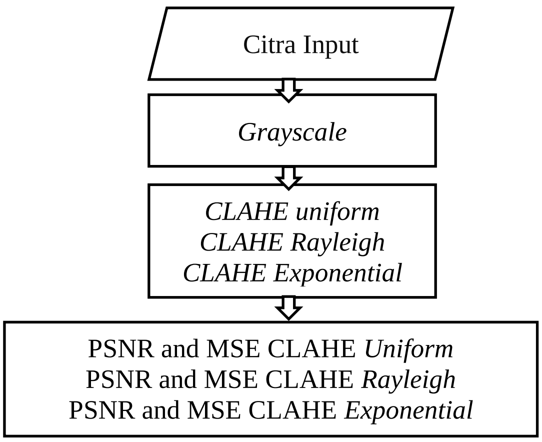


Figure 3. CLAHE process

```
Pseudocode 1. Program CLAHE
Input: original citra
Output:CLAHE image
   1. Process grayscale with rgb2gray.
   2. Grayscale histogram and show rgb2gray image
   3. U=adapthisteq(ImageAbu,'clipLimit',0.02,'Distribution','un
      iform');
   4. R=adapthisteq(ImageAbu,'clipLimit',0.02,'Distribution','ra
      yleigh');
   5. E=adapthisteq(ImageAbu,'clipLimit',0.02,'Distribution','ex
      ponential');
```

Pseudocode Description:

1. Conversion to Grayscale
   The RGB image is converted to grayscale using the rgb2gray function. This is done because CLAHE is generally applied to single intensity images (1 channel). The rgb2gray function calculates pixel intensity based on a combination of R, G, and B channels.
2. Histogram and Image Display
   The grayscale histogram is used to see the intensity distribution before contrast enhancement. This visualization helps to visually compare the original image and the CLAHE results.
3. CLAHE with Uniform Distribution
   The adapthisteq function is a CLAHE implementation in MATLAB. The clipLimit parameter controls the maximum amount of contrast enhancement so as not to cause noise. Distribution = 'uniform' means that the histogram in each tile block will be flattened uniformly. The result U is an image with uniform contrast enhancement.
4. CLAHE with Rayleigh Distribution
   The Rayleigh distribution is more suitable for asymmetric (unbalanced) data. This approach can be more effective in clarifying certain dark/light parts of the X-ray image.
5. CLAHE with Exponential Distribution
   Exponential distribution can enhance certain intensities that are rarely seen, making specific details clearer. This is useful if important parts of the X-ray (e.g. COVID-19 infection) have low intensity.

Testing was carried out using PSNR and MSE parameters with formula 3 and formula 4.

$$MSE = \frac{1}{K.L.M}\sum_{X=1}^{K}\sum_{y=1}^{L}\sum_{z=1}^{M}\left[\left(H_{x,y,z} - H'_{x,y,z}\right)^2\right] \quad (3)$$

```
Pseudocode 2. MSE and PSNR  programs
Input: CLAHE image, grayscale image
Output:MSE, PSNR
   1. MSE and PSNR  CLAHE Uniform
      MSE = sum(sum((ImageAbu-U.^2))/(row*col);
      PSNR = 10*log10(256*256/MSE);
   2. MSE and PSNR  CLAHE Rayleigh
      MSE = sum(sum((ImageAbu-R.^2))/(row*col);
      PSNR = 10*log10(256*256/MSE)
   3. MSE and PSNR  CLAHE Exponential
      MSE = sum(sum((ImageAbu-E.^2))/(row*col);
      PSNR = 10*log10(256*256/MSE);
```

Where MSE is the Mean Square Error of the image. Where K and L are the image resolution, M is the number of image channels, H(x, y, z) is the pixel value of the original image at coordinates x, y and channel z, H′ is the output/processing image [25].

$$PSNR = 10\ Log_{10}\left(\frac{max^2}{MSE}\right) \quad (4)$$

where PSNR is the Image Peak Signal to Noise Ratio. The MSE and PSNR formulas are interpreted in Pseudocode 2.

2.3 Dataset

The research came from the radiology department of Embung Fatimah Hospital, Batam. Research uses secondary data. Data was obtained from interviews and documentation of X-Ray X-ray equipment. Documentation in the form of images of 10 lung image samples from COVID-19 patients and 10 lung image samples from healthy patients. Samples were obtained using a Philips brand X-Ray machine with type *mobile*, serial no. Practix-360. The equipment is operated by 1 radiology specialist and 10 staff *radiographers.* The resulting file from the machine *X-Ray* berupa DICOM (Digital Imaging and Communications in Medicine). The X-ray data obtained from Embung Fatimah Hospital is in DICOM format which is exported into JPEG/JPG format via the MicroDicom application, which is an application for viewing X-ray, ultrasound and MRI results, along with patient information, and can also be exported to other formats such as TIF, BMP and so on. The file is exported to JPEG/JPG with a size of 1024 x2048 pixels and cropped. Image acquisition tools and data samples can be shown in Figure 4 and Figure 5.

2.4 Performance Metrics

CLAHE method in image processing, two metrics that are often used to assess image quality performance are PSNR (Peak Signal-to-Noise Ratio) and MSE (Mean Squared Error). Both measure the extent to which the processed image (output) differs from the original image (input). CLAHE increases the contrast, which can significantly change the histogram. This can result in a decrease in PSNR, because CLAHE changes the pixel distribution (rather than simply maintaining similarity to the original image). MSE increases, because there is a deviation of pixels from the original image. However, the increase in contrast (visual perception) can still be considered subjectively better, even though the PSNR and MSE appear "worse". The criteria for measuring CLAHE results with PSNR and MSE can be shown in Table 1.

Figure 4. *X-Ray* Philips Machine, *Mobile* Seri Practix-360 Type
(Source: Embung Fatimah Hospital)

(a)

(b)

Figure 5. (a) COVID-19 Patient Image (b) Healthy/Normal Patient Image

Tabel 1. Criteria for Measuring CLAHE Results with PSNR and MSE

Criteria	PSNR Value	MSE Value
Successful	If the PSNR of the CLAHE image> 30 dB	If the MSE value of the CLAHE image is getting lower and approaching 0 (zero)
Not Successful	If the PSNR of the CLAHE image < 30 dB	If the MSE value of the CLAHE image is higher and moves away from 0 (zero)

(a). Original Image (b).Citra Grayscale

Figure 6. Original Image and Grayscale

(a). CLAHE Uniform (b). Rayleigh (c). CLAHE Exponential

Figure 7. Image result

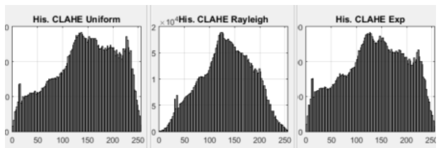


Figure 8. Histogram

Figure 9. PSNR and MSE

3. Results and Discussions

3.1 Results

After CLAHE identification has been carried out, starting from the input image, CLAHE processing and testing with MSE and PSNR parameters, changes can be seen in the image. The image input process then continues with conversion to *grayscale.* The results are shown in Figures 6a and 6b. Process *grayscale* Continue to CLAHE. In the CLAHE process, images are processed into 3 types of distribution, namely CLAHE *Uniform*, CLAHE *Rayleigh* and CLAHE Exponential. The CLAHE image results are shown in Figures 7a, 7b and 7c. Next, displays the histogram of each CLAHE, each type of distribution shown by the histogram in Figure 8. Finally, the results of CLAHE image testing with MSE and PSNR parameters in Figure 9.

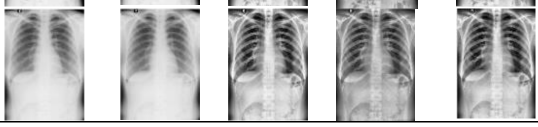
The results of the image processing using the CLAHE (Contrast Limited Adaptive Histogram Equalization) method demonstrate a significant improvement in the quality of lung images from both COVID-19 patients and healthy patients. The enhanced contrast and visibility of previously unclear images were clearly observable after processing with CLAHE, indicating its potential for improving medical imaging, especially in the context of identifying lung conditions like COVID-19. From the results, it is evident that the CLAHE method successfully equalizes the image histogram, stretching pixel values across the full intensity range (from 0 to 255), which contributes to better contrast and image clarity. This is particularly important in medical imaging where subtle differences in tissue characteristics can be critical for diagnosis.

3.2 Discussions

The improvement in image quality was quantified by two metrics: MSE (Mean Squared Error) and PSNR (Peak Signal-to-Noise Ratio). Both metrics provide an objective way to assess the effectiveness of the CLAHE method. The overall results of the research on 10 samples of COVID-19 and healthy images can be shown in the Table 2.

The results obtained from the test data are then tested for accuracy levels. The image results using the CLAHE method show an increase in quality. Images that lack clear contrast become clearly visible to the visual sense. The histogram image of each CLAHE experiences equalization from the values 0 to 255 which are visible in the resulting histogram image. The results of CLAHE image processing show that the contrast quality of 10 lung image samples from COVID-19 patients and healthy patients was successfully improved. This is evidenced by the MSE value approaching zero and the PSNR value exceeding 30 dB in Table 1.

Table 2 CLAHE Test Results

No	Original Image	Citra Grayscale	*CLAHE uniform*	*CLAHE Rayleigh*	*CLAHE Exponential*	*PSNR CLAHE uniform*	*PSNR CLAHE Rayleigh*	*PSNR CLAHE Exponential*	*MSE CLAHE uniform*	*MSE CLAHE Rayleigh*	*MSE CLAHE Exponential*
COVID-19 patient											
1						154.581	186.303	176.023	26.2732	25.4626	25.7091
2						162.85	200.923	187.062	26.0469	25.1345	25.4449
3						119.168	166.75	147.678	27.4032	25.9441	26.4717
4						153.193	185.049	176.09	26.3124	25.4919	25.7074
5						168.623	204.905	191.986	25.8956	25.0493	25.3321
6						163.204	222.9	192.323	26.0375	24.6837	25.3245
7						137.104	170.502	158.955	26.7943	25.8475	26.1521
8						156.264	199.359	184.121	26.2262	25.1684	25.5138
9						164.937	203.271	188.357	25.9916	25.0841	25.415
10						176.409	225.824	203.194	25.6996	24.6271	25.0857

No	Original Image	Citra Grayscale	*CLAHE uniform*	*CLAHE Rayleigh*	*CLAHE Exponential*	*PSNR CLAHE uniform*	*PSNR CLAHE Rayleigh*	*PSNR CLAHE Exponential*	*MSE CLAHE uniform*	*MSE CLAHE Rayleigh*	*MSE CLAHE Exponential*
Healthy Patients											
1						98.5786	119.671	119.163	28.227	27.3849	27.4034
2						74.7162	89.9304	90.4381	29.4307	28.6257	28.6013
3						103.799	123.424	126.144	28.0029	27.2508	27.1561
4						118.445	162.718	144.313	27.4296	26.0504	26.5717

5						107.628	144.873	131.776	27.8455	26.5549	26.9664
6						96.2568	116.193	113.811	28.3305	27.513	27.6029
7						89.4316	105.836	107.013	28.6499	27.9185	27.8704
8						102.519	124.462	124.089	28.0567	27.2144	27.2275
9						97.7702	124.041	119.59	28.2627	27.2292	27.3879
10						93.5239	111.015	113.322	28.4556	27.711	27.6216

The average MSE results of 10 COVID-19 patient samples starting from CLAHE Uniform, Rayleigh, Exponential and respectively are as follows 26.27, 25.25 and 25.62. The average MSE results of 10 healthy patient samples starting from CLAHE Uniform, Rayleigh, Exponential and respectively are as follows 28.27, 27.35 and 27.44. The average PSNR results of 10 COVID-19 patient samples CLAHE Uniform, Rayleigh, Exponential respectively are as follows 155.63, 196.58 and 180.58. The average PSNR results of 10 healthy samples CLAHE Uniform, Rayleigh, Exponential respectively are as follows 98.27, 122.22 and 118.97. is said to be successful if the PSNR of the CLAHE image is > 30 dB. If the MSE value of the CLAHE image is getting lower and approaching 0 (zero). Based on the average MSE and PSNR results, all have been successful. CLAHE Rayleigh is the best CLAHE. The accuracy results obtained based on Table 3 are 100%.

Table 3. PSNR and MSE Test Results

No.	PSNR				MSE			
	COVID-19 patient							
	PSNR CLAHE uniform	*PSNR CLAHE Rayleigh*	*PSNR CLAHE Exponential*	Criteria	*MSE CLAHE uniform*	*MSE CLAHE Rayleigh*	*MSE CLAHE Exponential*	Criteria
1	154.581	186.303	176.023	Successful	26.2732	25.4626	25.7091	Successful
2	162.85	200.923	187.062	Successful	26.0469	25.1345	25.4449	Successful
3	119.168	166.75	147.678	Successful	27.4032	25.9441	26.4717	Successful
4	153.193	185.049	176.09	Successful	26.3124	25.4919	25.7074	Successful
5	168.623	204.905	191.986	Successful	25.8956	25.0493	25.3321	Successful
6	163.204	222.9	192.323	Successful	26.0375	24.6837	25.3245	Successful
7	137.104	170.502	158.955	Successful	26.7943	25.8475	26.1521	Successful
8	156.264	199.359	184.121	Successful	26.2262	25.1684	25.5138	Successful
9	164.937	203.271	188.357	Successful	25.9916	25.0841	25.415	Successful
10	176.409	225.824	203.194	Successful	25.6996	24.6271	25.0857	Successful
Average	**155.63**	**196.58**	**180.58**	**Successful**	**26.27**	**25.25**	**25.62**	**Successful**
	Healthy Patients							
1	98.5786	119.671	119.163	Successful	28.227	27.3849	27.4034	Successful
2	74.7162	89.9304	90.4381	Successful	29.4307	28.6257	28.6013	Successful
3	103.799	123.424	126.144	Successful	28.0029	27.2508	27.1561	Successful
4	118.445	162.718	144.313	Successful	27.4296	26.0504	26.5717	Successful
5	107.628	144.873	131.776	Successful	27.8455	26.5549	26.9664	Successful
6	96.2568	116.193	113.811	Successful	28.3305	27.513	27.6029	Successful
7	89.4316	105.836	107.013	Successful	28.6499	27.9185	27.8704	Successful
8	102.519	124.462	124.089	Successful	28.0567	27.2144	27.2275	Successful
9	97.7702	124.041	119.59	Successful	28.2627	27.2292	27.3879	Successful
10	93.5239	111.015	113.322	Successful	28.4556	27.711	27.6216	Successful
Average	**98.27**	**122.22**	**118.97**	**Successful**	**28.27**	**27.35**	**27.44**	**Successful**
			Accuracy				$\frac{\mathbf{20}}{\mathbf{20}} = \mathbf{100\%}$	

Based on the image testing results, the CLAHE method is feasible and effective for increasing image contrast of the lungs of COVID-19 patients. This can be seen from the image after the CLAHE process which is clearer than the original image and there is an even distribution of the image histogram. MSE results close to 0 and PSNR values >30 dB are indicators of the success of the CLAHE method in improving the lung image quality of COVID-19 patients and Healthy Patients [26].

The fact that CLAHE significantly improves image clarity and contrast for both COVID-19 and healthy patients highlights its robustness and versatility in medical image processing [27]. By enabling a clearer view of lung tissue, it helps healthcare professionals to potentially detect irregularities or abnormalities with greater accuracy. This improvement in contrast could be particularly useful for detecting early signs of diseases like COVID-19, where subtle changes in the lung structure may be important indicators. Moreover, the consistency of the results across both patient groups COVID-19 and healthy patients further supports the general applicability of the CLAHE method. The method is not only effective for enhancing lung images of COVID-19 patients but also proves beneficial for improving images of healthy patients, showing its broad potential for use in various medical imaging scenarios.

In conclusion, the CLAHE method is proven to be an effective tool for enhancing the contrast and quality of lung images, as evidenced by the improved MSE and PSNR values and the subjective improvement in visual clarity. With the Rayleigh distribution providing the best performance, this method can be considered a viable and reliable technique for medical image enhancement, particularly in the context of respiratory diseases such as COVID-19.

4. Conclusion

CLAHE effectively improves the image quality of the lungs of COVID-19 and healthy patients by increasing the contrast. This helps to see clearly for disease detection. The resulting CLAHE image is visually clearer compared to the original image. The MSE results of the CLAHE image are of type *Uniform*, *Rayleigh* and *Exponential* close to 0 and the PSNR result is >30 dB which means the resulting image good and similar to the original. MSE and PSNR CLAHE values *Rayleigh* is the best compared to CLAHE type *Uniform* and *Exponential* with 85% accuracy. For further research improvement use the X-ray images processed with CLAHE as input for AI-based classification models (such as CNN) to distinguish between COVID-19 and healthy patients; also assess whether the improvement in image quality has a direct impact on the accuracy of automatic diagnosis.

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