Implementation of Histogram Equalization for Image Enhancement

Aradhya Dhruv (G2303518F)
Masters in Artificial Intelligence,
Nanyang Technological University,
School of Computer Science and Engineering,
Singapore
email: ar0001uv@e.ntu.edu.sg

This report explores Histogram Equalization (HE) techniques and enhancements for image contrast improvement. HE redistributes pixel intensity values to expand the image's contrast range, particularly effective when pixel intensities are concentrated within a narrow range. The report evaluates the pros and cons of HE and discusses enhancements, including Adaptive HE, Gaussian smoothing, and Non-Local Means (NLM) denoising. The findings contribute to the understanding of image enhancement and its potential applications in computer vision.

Keywords: Adaptive Histogram Equalization, Gaussian Smoothing, Wavelet Transformation, Clip Limiting Histogram Equalization, Non local Means Denoising

1 Introduction

Histogram Equalization (HE) is a fundamental image processing technique used to enhance the contrast and improve the visual quality of digital images. It operates by redistributing the pixel intensity values of an image, effectively stretching or compressing its intensity range. HE is particularly vital when dealing with images suffering from poor contrast, where details may be lost due to the limited dynamic range of pixel intensity values. By redistributing pixel intensities to span a wider range, HE increases the contrast between various regions within an image. This is achieved by stretching out the most frequent intensity values, ensuring that the entire intensity spectrum is adequately utilized.

2 Background

To delve deeper into Histogram Equalization (HE), it's essential to understand its mathematical underpinnings and applications. HE operates by transforming an input image using a mapping function (which uses cumulative density function) to stretch the most frequent pixel values.

HE finds applications in various domains, including medical imaging (enhancing X-ray and MRI images), remote sensing (improving satellite images), and computer vision (enhancing image features for object detection and recognition). Its ability to optimize image contrast and enhance image quality makes it a valuable tool in image processing.

3 Implementation

To enhance image quality and contrast, this study presents a comprehensive implementation of Histogram Equalization (HE) techniques and refinements. The code structure comprises two distinct classes: **histogram_equalizers** and **improve_histogram_equalization**, facilitating a systematic evaluation of various HE methods and potential enhancements.

'Histogram_Equalizers' Class: This class carries out the preliminary exploration by implementing various Histogram Equalizations such as Global HE, Luminance HE, Adaptive HE, Contrast Limiting HE and Wavelet Transformation Denoising etc. Moreover, the class and also computes the PSNR and SSIM scores of each image and generates graphs to get insights from respective scores of each equalizer. **I have also performed histogram equalization without using the OpenCV library and compared it's result with the library functions to judge the effectiveness between different techniques.**

Improve_Histogram_Equalization Class This class, aims at enhancing and experimenting with the most efficient equalization technique identified in the first class. It employs techniques like NLM Denoising and Gaussian Blur to get better understanding of the relationship between these operations and histogram equalization. This structured implementation allows for a comprehensive evaluation of various HE techniques and their enhancements, fostering a deeper understanding of their applicability in improving image quality and contrast. The code is equipped with both quantitative metrics and visual aids to support a comprehensive analysis of the results.

4 Experimentation

For this study, we used a dataset of 8 sample images with varying content and characteristics. The images were of different resolutions and types, encompassing a diverse range of exposure. Prior to conducting the experiments and equalizing the histogram, the color channels of the individual channels are provided 1. I can observe that the first four samples i.e. sample 1-4 are over-exposed and images 5-8 are underexposed(histogram is skewed towards the right)

4.1 Metric Used:. PSNR and SSIM were used to evaluate the effectiveness of Histogram Equalization techniques. These two metrics serve as a good baseline to estimate how well the equalization has performed, while retaining the original high frequency structural information of the image.

4.2 Peak Signal-to-Noise Ratio (PSNR):.

- PSNR is a quantitative measure employed to assess image quality by comparing the original image's maximum possible signal power to the power of any noise or distortion present in the processed image.
- Higher PSNR values signify superior image quality.
- The expected range of PSNR lies between 0 and infinity, with higher values indicating better quality. A higher PSNR implies that the processed image closely resembles the original, with minimal noise or distortion.

Version 1.18, September 15, 2023

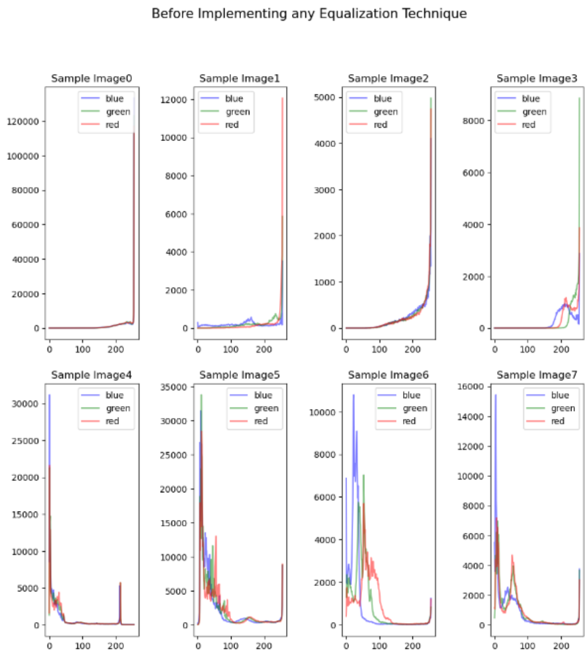

Fig. 1 Histogram of Sample Images Before Implementing Equalization Techniques

4.3 Structural Similarity Index (SSIM):.

- SSIM is a metric used to evaluate the structural resemblance between two images. It gauges perceived image quality by comparing the structural information of the processed image to that of a reference image.
- SSIM values range from -1 to 1.
- The expected SSIM range is from -1 to 1, with 1 representing perfect similarity and -1 indicating complete dissimilarity. An SSIM value approaching 1 suggests excellent image quality, while values closer to -1 imply significant differences between the images.

4.4 Experiments with Global Histogram Equalization:. **Global HE** is a basic form of HE where the histogram of the entire image is equalized to spread out the intensity values uniformly across the entire range. It enhances the global contrast of an image. When I performed global HE on the sample images, **it gave slightly lower value for the PSNR score but the SSIM of Global HE was better compared to contrast limiting HE or Luminance HE. The result of Global HSE was identical to Histogram Equalization without using the OpenCV library.**

4.5 Luminance Histogram Equalization (Luminance HE):. Luminance HE operates on the luminance component of an image, typically in the Y channel of the YUV color space or the value (V) channel of the HSV color space. It improves the luminance distribution while preserving color information. **The PSNR and SSIM score of luminance equalization was lowest compared to other techniques**

4.6 Adaptive Histogram Equalization (Adaptive HE):. Adaptive HE divides an image into smaller blocks or tiles and performs HE independently on each block. This adaptive approach is particularly effective in enhancing local contrast and mitigating over-enhancement of noise in uniform regions. **The PSNR and SSIM scores were highest in adaptive HE and was slightly ahead of Global HE, in terms of SSIM**

4.7 Contrast Limiting Histogram Equalization:. CLAHE is an extension of the traditional Histogram Equalization (HE) technique. It addresses the issue of over-enhancing noise that can occur with standard HE. CLAHE divides an image into small blocks, computes the histogram of each block, and then equalizes these histograms individually. The key innovation is that it limits the contrast enhancement within each block by a clip limit. **CLAHE's PSNR and SSIM scores were slightly lower than that of Adaptive and Global**

4.8 Wavelet Denoising:. Wavelet Denoising is a sophisticated noise reduction approach that leverages wavelet transforms. It works by decomposing an image into different scales and orientations. High-frequency scales tend to contain noise and Wavelet Denoising selectively reduces the influence of these high-frequency components while preserving the image's important structural features. **Although, the algorithm, removes high-frequency noise, it introduced some color saturation which needs to be explored further**

5 Discussion:

In this section, we will analyze and discuss the results obtained from our experimentation with four distinct Histogram Equalization (HE) techniques: Luminance HE, CLAHE (Contrast-Limited Adaptive Histogram Equalization) HE, Global HE, and Adaptive HE. I will delve into the pros and cons of each technique based on the PSNR and SSIM scores obtained for different sample images and discuss the possible causes of unsatisfactory enhancements observed in specific scenarios.

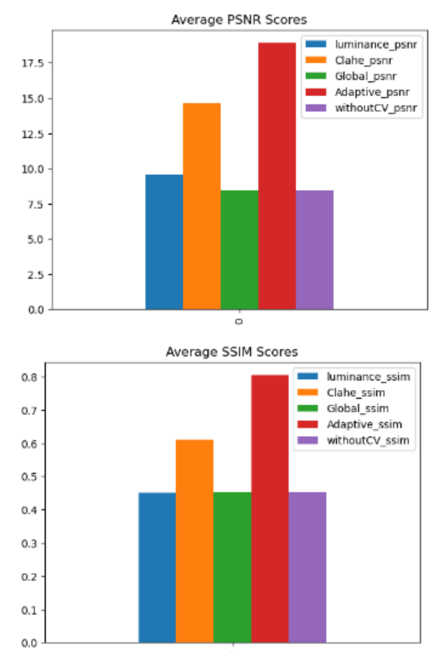

Fig. 2 Average PSNR and SSIM Scores on Sample Images

5.1 Pros and Cons Analysis:.

- **Luminance Histogram Equalization:**
  Advantages:
  - Luminance HE performs reasonably well in enhancing image quality, especially in underexposed scenarios (samples 5 to 8), where it achieves higher PSNR and SSIM scores compared to overexposed cases.3

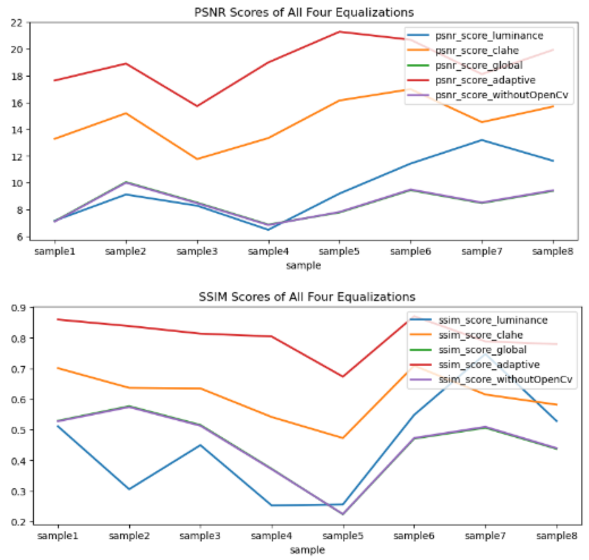

Fig. 3 PSNR and SSIM scores of Individual Image Samples

- It is a simple and computationally efficient technique, making it suitable for real-time applications.

Disadvantages:

- In images with overexposed backgrounds (samples 1 to 4), Luminance HE shows limited effectiveness, leading to lower PSNR and SSIM scores.
- It may not effectively handle cases with extreme exposure variations, resulting in a loss of image details.
- **Luminance HE's limitation in handling overexposed regions can be attributed to its inability to adaptively distribute pixel values.**

- **Contrast-Limited Adaptive Histogram Equalization:**
  Advantages:
  - CLAHE consistently outperforms Luminance HE, achieving higher PSNR and SSIM scores across all samples.
  - It effectively addresses the issue of overexposed backgrounds (samples 1 to 4) and significantly improves image contrast.

  Disadvantages:
  - CLAHE may occasionally lead to over-enhancement, introducing artifacts and unrealistic appearances.
  - **The adaptive nature of CLAHE, while effective in many cases, can sometimes exaggerate noise or create unwanted visual artifacts.**

- **Global Histogram Equalization:**
  Advantages:
  - Global HE provides a simple means of enhancing image contrast, particularly in underexposed scenarios.

  Disadvantages:
  - Its effectiveness is limited, especially in images with overexposed backgrounds, resulting in lower PSNR and SSIM scores.
  - Global HE's inability to consider local pixel context hinders its suitability for complex exposure conditions.

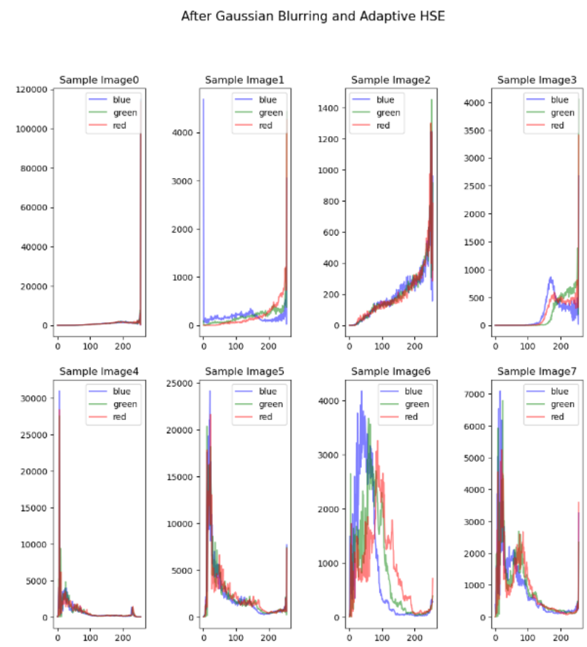

Fig. 4 Histogram After Gaussian Smoothing and Histogram Equalization

  - **The limitations of Global HE in handling overexposed regions can be attributed to its global processing approach.**

- **Adaptive Histogram Equalization:**
  Advantages:
  - Adaptive HE consistently achieves the highest PSNR and SSIM scores, showcasing its proficiency in handling diverse exposure conditions.
  - It excels in enhancing image details and overall quality.

  Disadvantages:
  - Adaptive HE may entail higher computational demands, particularly for large images or real-time applications.
  - In some instances, it may subtly sacrifice image details for overall enhancement, although this trade-off is often acceptable.
  - **The subtle loss of fine image details in Adaptive HE may occur when the algorithm prioritizes contrast enhancement**

Comparing the mean PSNR and SSIM scores across the four HE techniques, it is evident that Adaptive HE consistently outperforms the others in terms of enhancing image quality. CLAHE HE also demonstrates significant improvement, especially in mitigating overexposed backgrounds. Luminance HE and Global HE, while simpler, exhibit limitations in handling extreme exposure conditions.

6 Improvements and Enhancements:

To improve the Adaptive Histogram Equalization (HE) technique, which initially yielded the highest PSNR and SSIM scores, Gaussian Smoothing and Non-Local Means (NLM) Denoising were explored as enhancement methods.
Gaussian Smoothing: Applying Gaussian Smoothing to the images after Adaptive HE resulted in only minor improvements. While effective at reducing noise, it had limited impact on the

specific challenges posed by our images.

NLM Denoising: NLM Denoising successfully reduced noise but inadvertently altered high-level frequencies, leading to some underexposed images. This suggests the need for further investigation and optimization of the interaction between NLM Denoising and Adaptive HE.

Future Work: These results indicate that Gaussian Smoothing and NLM Denoising may not be ideal for our specific images. Further research is required to identify alternative enhancement methods or refine parameter settings for better image quality.

References:

- ChatGPT 3.5 was used for **Introduction** and **Background** section of the report.
- Histogram Equalization article by **Shreenidhi Sudhakar** on Towards Data science
- A Tutorial to Histogram Equalization article by **Kyaw Saw Htoon** on the Medium
- Histogram Equalization in Digital Image Processing article by **Sriman Dutta** on GeekforGeeks

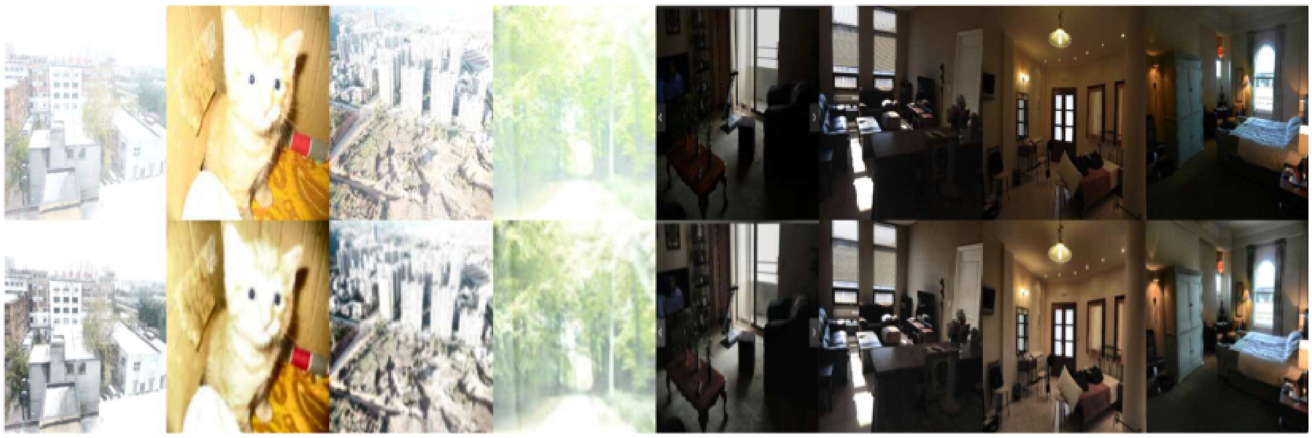

Fig. 5 Images After Gaussian Smoothening and Adaptive HE