DEPARTMENT OF ROBOTICS & MECHATRONICS ENGINEERING

University of Dhaka

Course : Digital Image Processing an Robot Vision

Course Code : 4112

Lab Task 1 : Image Enhancement by different techniques

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Objective

- The primary objectives of this lab task are:
- To understand and implement histogram-based image enhancement techniques
- To apply histogram equalization for improving image contrast
- To implement CLAHE (Contrast Limited Adaptive Histogram Equalization) for localized enhancement
- To explore various thresholding techniques for image segmentation
- To analyze and compare different image processing methods

Introduction

Image enhancement is a fundamental operation in digital image processing that aims to improve the visual quality of images. Poor lighting conditions, improper camera settings, or aging of photographs can result in images with low contrast and poor visibility. Histogram equalization is a powerful technique that redistributes pixel intensities across the entire dynamic range, thereby enhancing the overall contrast of the image.

In this lab, we process four different images through a series of enhancement and thresholding operations to demonstrate the effectiveness of various image processing techniques.

Methodology

Image Acquisition and Preprocessing

Four grayscale images were selected for this experiment, each exhibiting different contrast characteristics and intensity distributions. The images were loaded using OpenCV library in Python.

Figure 1: Original input images

Histogram Analysis

Histograms provide a graphical representation of the pixel intensity distribution in an image. By analyzing the histogram, we can understand the contrast, brightness, and dynamic range of an image.

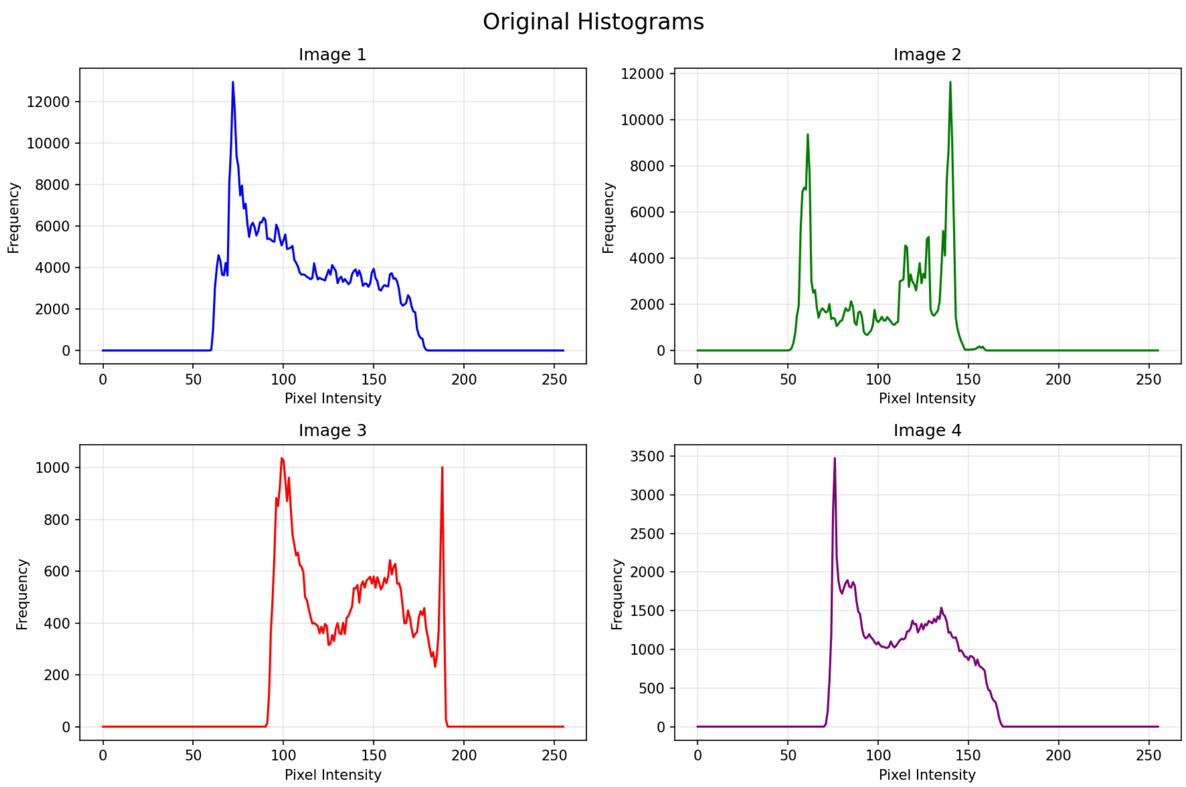

Figure 2: Histogram distribution of original images

Observations:

1. Images with narrow histogram distributions indicate low contrast
2. Concentrated histograms in specific intensity ranges suggest poor utilization of the available dynamic range
3. The original histograms reveal that most images suffer from limited contrast, making them ideal candidates for enhancement

Histogram Equalization

Histogram equalization is a method that redistributes pixel intensities to achieve a more uniform histogram distribution. The technique uses the cumulative distribution function (CDF) to map the original intensity values to new values that span the entire intensity range (0-255).

Mathematical Foundation:
The equalized image is obtained using:
$h(v) = round((CDF(v) - CDFmin) / (M \times N - CDFmin) \times (L - 1))$
Where:

CDF(v) = cumulative distribution function

M × N = total number of pixels

L = number of intensity levels (256 for 8-bit images)

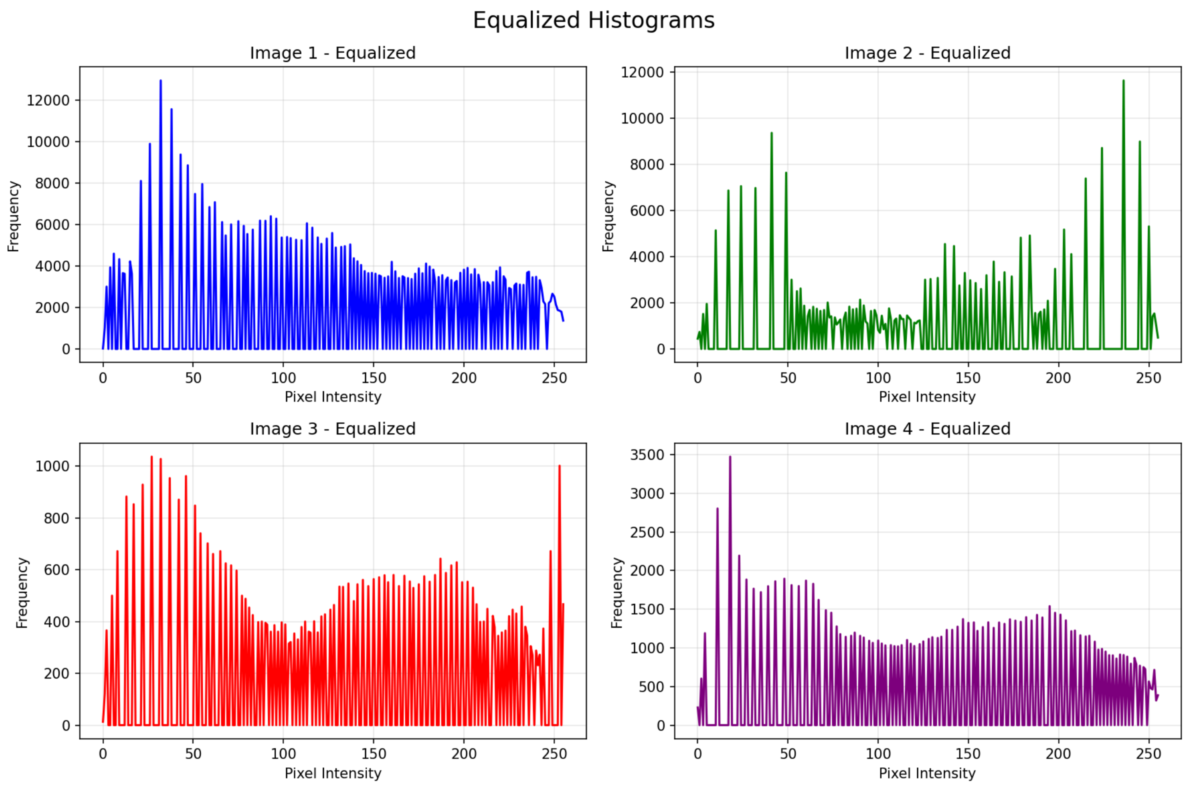

Figure 3: Images after histogram equalization

Figure 4a: Before and after comparison for Image 1

Figure 4b: Before and after comparison for Image 2

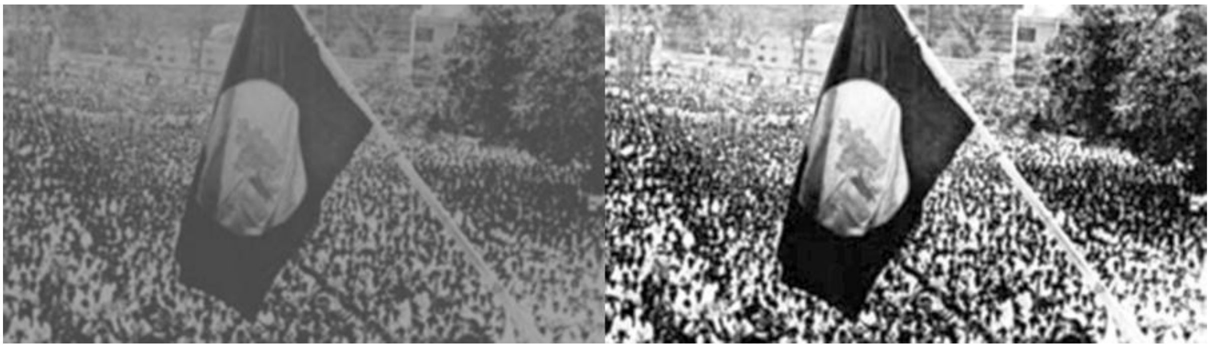

Figure 4c: Before and after comparison for Image 3

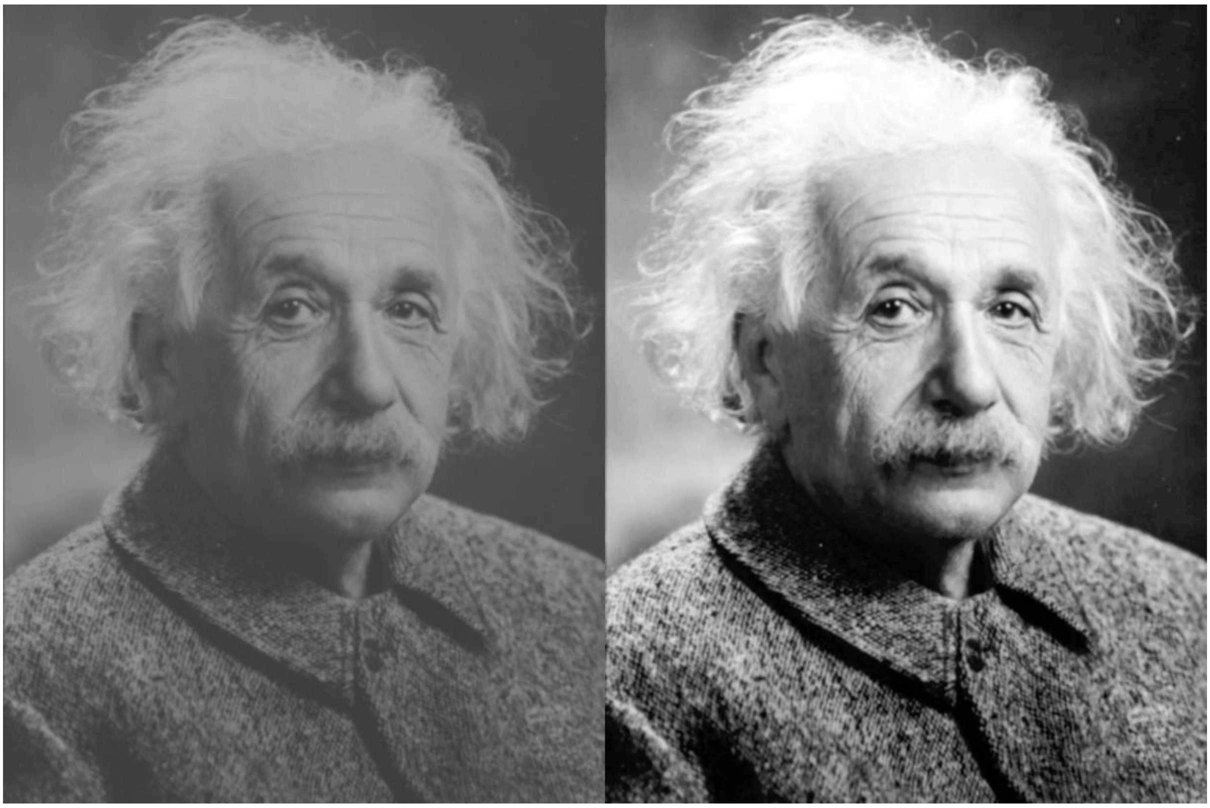

Figure 4d: Before and after comparison for Image 4

Results:

1. The equalized images show significantly improved contrast
2. Histograms are now spread across the entire intensity range
3. Previously hidden details become visible
4. However, some images may exhibit over-enhancement in certain regions

CLAHE (Contrast Limited Adaptive Histogram Equalization)

While global histogram equalization improves overall contrast, it can lead to over-amplification of noise in relatively homogeneous regions. CLAHE addresses this limitation by:

1. Dividing the image into small tiles (typically 8×8)
2. Applying histogram equalization to each tile independently
3. Limiting contrast amplification using a clip limit parameter
4. Using bilinear interpolation to eliminate artificial boundaries

Parameters Used:

- Clip Limit: 40
- Tile Grid Size: 8×8 (default)

Figure 5: Images after CLAHE enhancement

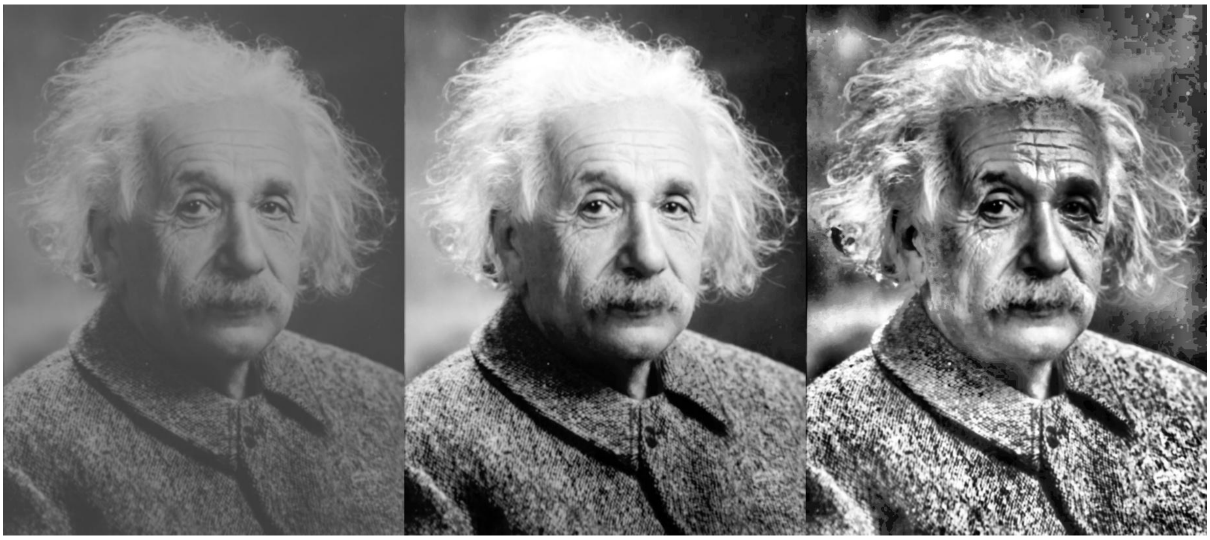

Figure 6a: Full progression for Image 1 (Original → Equalized → CLAHE)

Figure 6b: Full progression for Image 2 (Original → Equalized → CLAHE)

Figure 6c: Full progression for Image 3 (Original → Equalized → CLAHE)

Figure 6d: Full progression for Image 4 (Original → Equalized → CLAHE)

Advantages of CLAHE:

1. Preserves local contrast better than global histogram equalization
2. Reduces noise amplification through contrast limiting
3. Provides more natural-looking enhancement
4. Better suited for images with varying lighting conditions

Thresholding Techniques

Thresholding is a fundamental segmentation technique that converts grayscale images into binary images. Different thresholding methods serve different purposes depending on the application.

Global Thresholding Methods

We applied six different thresholding techniques on the CLAHE-enhanced images with a threshold value of 80:

1. Binary Thresholding:

$$dst(x,y) = maxVal \text{ if } src(x,y) > threshold \text{ else } 0$$

2. Binary Inverse Thresholding:

$$dst(x,y) = 0 \text{ if } src(x,y) > threshold \text{ else } maxVal$$

3. Truncate Thresholding:

$$dst(x,y) = threshold \text{ if } src(x,y) > threshold \text{ else } src(x,y)$$

4. To-Zero Thresholding:

$$dst(x,y) = src(x,y) \text{ if } src(x,y) > threshold \text{ else } 0$$

5. To-Zero Inverse Thresholding:

$$dst(x,y) = 0 \text{ if } src(x,y) > threshold \text{ else } src(x,y)$$

6. Otsu's Thresholding:

- Automatically determines optimal threshold value
- Minimizes intra-class variance of foreground and background pixels

Figure 7: Binary, Binary Inverse, and Truncate thresholding results

Figure 8: To-Zero, To-Zero Inverse, and Otsu thresholding results

Adaptive Thresholding

Unlike global thresholding which uses a single threshold value for the entire image, adaptive thresholding calculates different thresholds for different regions of the image. This is particularly useful for images with varying illumination.

Two Methods Implemented:

1. Adaptive Mean Thresholding:

Threshold = mean of neighborhood area - constant C

Better for images with gradual lighting variations

2. Adaptive Gaussian Thresholding:

Threshold = weighted sum (Gaussian window) - constant C

Provides smoother results with better noise handling

Parameters Tested:

- Block sizes: 11, 13, 21, 31 pixels
- Constant C values: 2, 3, 4, 5

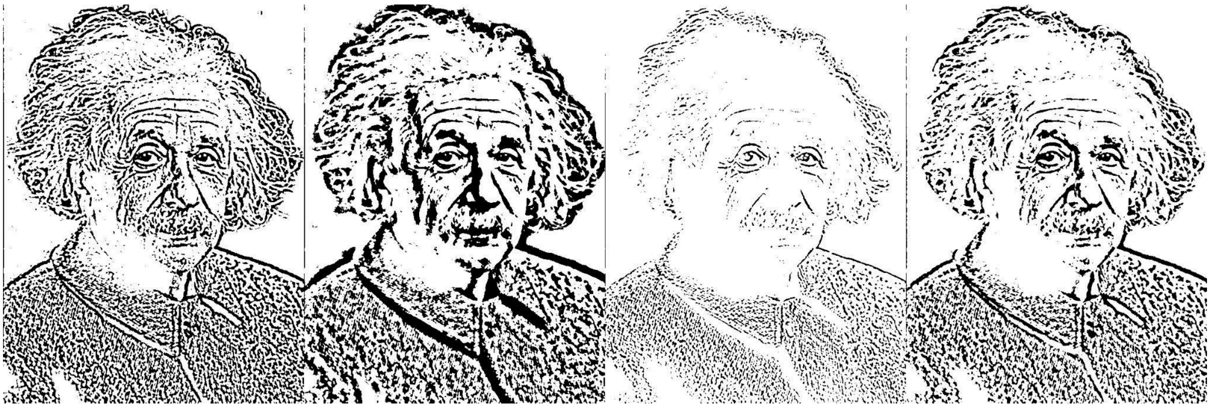

Figure 9: Adaptive thresholding results for Image 1 with different parameters

Figure 10: Adaptive thresholding results for Image 2 with different parameters

Otsu's Method on All Images

Otsu's method was applied to all four original grayscale images to demonstrate automatic threshold selection.

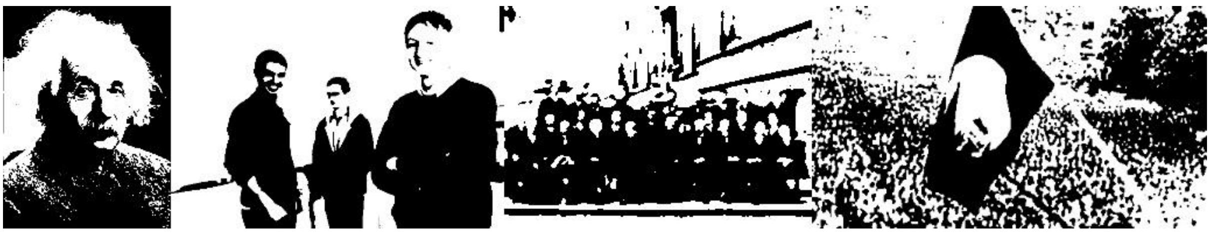

Figure 11: Otsu's automatic thresholding applied to all four images

Otsu's Algorithm:

- Compute histogram and probabilities of each intensity level
- For each possible threshold, calculate between-class variance
- Select threshold that maximizes between-class variance
- This minimizes intra-class variance, achieving optimal separation

Results and Discussion

Histogram Equalization Performance

Histogram equalization successfully enhanced the contrast of all four images by redistributing pixel intensities across the full dynamic range. The technique proved particularly effective for images with concentrated histogram distributions. However, some images showed over-enhancement in bright regions, demonstrating the limitation of global methods.

CLAHE Enhancement

CLAHE provided superior results compared to global histogram equalization by:

- Maintaining local contrast while enhancing overall visibility
- Preventing over-amplification of noise in uniform regions
- Producing more visually appealing and natural-looking images
- Better preserving fine details and textures

The clip limit parameter (40) effectively controlled the amount of contrast enhancement, preventing excessive amplification in homogeneous areas.

Thresholding Analysis

Different thresholding methods produced distinct results:

- Binary and Binary Inverse: Best for segmenting objects from backgrounds with clear intensity differences
- Truncate: Useful for removing bright spots while preserving darker details
- To-Zero methods: Helpful for background removal applications

Otsu's method: Provided optimal automatic threshold selection, particularly effective for bimodal histograms

Adaptive Thresholding

Adaptive thresholding demonstrated superior performance for images with non-uniform illumination. The local threshold calculation ensured that both bright and dark regions were properly segmented, which global thresholding failed to achieve.

The choice between Mean and Gaussian methods depends on:

- Image characteristics (noise level, illumination variation)
- Required processing speed
- Desired smoothness of boundaries

Conclusion

This lab successfully demonstrated various image enhancement and thresholding techniques:

- Histogram equalization effectively improved image contrast by utilizing the full intensity range
- CLAHE provided localized enhancement with better noise handling and more natural results
- Multiple thresholding techniques offered different approaches for image segmentation based on application requirements
- Adaptive thresholding proved essential for handling images with varying illumination

These techniques form the foundation of many computer vision applications including medical imaging, document processing, object detection, and image segmentation.

Code Implementation

The complete implementation was performed using Python with the following libraries:

- OpenCV (cv2): For image processing operations
- NumPy: For numerical computations
- Matplotlib: For visualization and plotting

The Complete Code is provided in the following github link :
https://github.com/SyedNazmusSakib-SNS/4112_Digital-Image-Processing/blob/main/lab_task.ipynb