Lab Report – Histogram Equalization & Matching

Objective

- To understand histogram equalization for contrast enhancement.
- To apply per-channel RGB and HSV Value-only equalization on color images.
- To implement histogram specification using a double Gaussian target distribution.
- To compare histograms, PDFs, and CDFs of input and processed images.

Introduction

Image enhancement plays a vital role in digital image processing as it improves the visual quality of images and makes them more suitable for analysis. One widely used approach is histogram equalization, which redistributes pixel intensities so that the image has better contrast and more visible details. In color images, this can be done either channel-wise in the RGB space or more naturally by equalizing only the Value component in the HSV space, which maintains color fidelity while enhancing brightness. Beyond equalization, histogram specification or matching is another powerful technique where the output image’s histogram is forced to follow a desired probability distribution. In this lab, we implemented both equalization and specification to understand their effects on contrast, brightness, and intensity distribution.

Theory

Histogram Concepts
- Histogram (H): frequency distribution of pixel intensities.
- PDF (p(x)): normalized histogram.
$p(x) = h(x)/N, \Sigma\, p(x) = 1$
- CDF (F(x)): cumulative sum of PDF.
$F(x) = \Sigma\, p(i)$

Classwork: RGB Histogram Equalization
- Split channels (R,G,B).
- Apply histogram equalization: $s_k = (L-1)*F(r_k)$.
- Merge equalized channels and compare histograms, PDFs, CDFs.

Assignment-1: RGB & HSV Equalization
- RGB equalization enhances each channel but may distort colors.
- HSV Value-only equalization enhances brightness while preserving color.

Assignment-2: Histogram Matching with Double Gaussian
- Target distribution: double Gaussian:
$p(x) = w1 * N(\mu1, \sigma1^2) + w2 * N(\mu2, \sigma2^2)$
- With $\mu1=30$, $\sigma1=8$, $\mu2=165$, $\sigma2=20$.
- Input CDF mapped to target CDF, LUT applied to form output.

Discussion

The experiments clearly showed the strengths and limitations of each approach. In RGB histogram equalization, contrast improvement was evident, but because each channel was equalized independently, the resulting images sometimes appeared color-distorted or unnatural. On the other hand, equalizing only the Value channel in HSV gave much more visually pleasing results, as it enhanced brightness and contrast while preserving the original hues and saturation. Histogram matching with a double Gaussian target distribution demonstrated a different concept: rather than spreading intensities uniformly, it reshaped the histogram to follow two distinct peaks, simulating controlled brightness regions. Comparing the input and output histograms, PDFs, and CDFs confirmed that equalization produces flatter, more uniform distributions, while specification precisely tailors the intensity distribution to the target function.

Conclusion

From this lab, it can be concluded that histogram-based techniques are effective tools for image enhancement and control of intensity distributions. Histogram equalization significantly improves global contrast but may introduce color distortion in RGB, whereas HSV Value-only equalization offers better naturalness and color preservation. Histogram specification provides a more flexible approach, as it allows the designer to impose a desired distribution, such as a double Gaussian, which can highlight or suppress certain ranges of brightness. Overall, the exercises reinforced both the theoretical understanding and practical application of these methods, showing their importance in fields ranging from photography to medical imaging where contrast and detail are critical.

References

1. Gonzalez & Woods, Digital Image Processing, 4th Edition.
2. Lab-3 Slide Deck: Histogram Equalization and Specification.
3. OpenCV Documentation: cv2.equalizeHist.