Different Types of Histogram Equalization Techniques

1. Basic Histogram Equalization (HE)

Overview:
Basic Histogram Equalization aims to enhance the contrast of an image by redistributing the intensity values so that they span the entire available range.

Mathematical Process:

1. **Histogram Calculation:**
   Let the image have intensity levels ranging from 0 to $L-1$. Calculate the histogram of the image, which gives the number of pixels n_k at each intensity level k.

   $$p_k = \frac{n_k}{MN}$$

   where:
   - p_k is the probability of occurrence of intensity level k.
   - $M \times N$ is the total number of pixels in the image.
2. **Cumulative Distribution Function (CDF):**
   Compute the cumulative distribution function (CDF) for each intensity level.

   $$C_k = \sum_{j=0}^{k} p_j$$

3. **Mapping to New Intensities:**
   Use the normalized CDF to map the original intensities to new values.

   $$s_k = (L-1) \times C_k$$

Advantages:

- Enhances overall image contrast.
- Simple and effective.

Limitations:

- Can cause unnatural brightness.
- Amplifies noise.

2. Adaptive Histogram Equalization (CLAHE)

Overview:
CLAHE enhances contrast by applying histogram equalization to small regions (tiles) of the image, limiting noise amplification by clipping the histogram.

Mathematical Process:

1. **Image Division:**
   Divide the image into non-overlapping tiles of size $m \times n$.
2. **Local Histogram Calculation:**
   Compute the histogram for each tile separately.
3. **Clip Limit Calculation:**
   Clip the histogram values to a predefined limit to reduce noise amplification. This clip limit can be set as a percentage of the total pixels in the tile.
4. **Redistribution and Mapping:**
   Distribute clipped histogram values evenly and map the pixel intensities as in basic HE.

Advantages:

- Enhances local details.
- Reduces lighting effects.

Limitations:

- May cause block artifacts.
- Higher computational cost.

3. Histogram Equalization Using OpenCV's Normalization

Overview:
Uses OpenCV's normalization functions to adjust pixel values, enhancing contrast.

Mathematical Process:

1. **Normalization Function:**
   Normalize pixel values to a standard range (e.g., 0-255).

   $$I' = \text{cv2.normalize}(I, 0, 255, \text{norm\_type=cv2.NORM\_MINMAX})$$

   where I is the input image and I' is the normalized output.

Advantages:

- Provides control over the process.
- Useful for machine learning preprocessing.

Limitations:

- Less adaptive than CLAHE.

4. Histogram Equalization on Color Images (YUV Method)

Overview:

This technique equalizes the luminance (Y) channel in the YUV color space.

Mathematical Process:

1. **Conversion to YUV Space:**
   Convert RGB image to YUV color space.
2. **Equalize the Luminance Channel (Y):**
   Apply HE to the Y channel and keep U and V unchanged.
3. **Convert Back to RGB:**
   Convert the image back to RGB color space.

Advantages:

- Maintains color balance.

Limitations:

- Slight color shifts may occur.

5. Bi-Histogram Equalization (BBHE)

Overview:

BBHE splits the histogram into two based on the mean intensity and equalizes each separately.

Mathematical Process:

1. **Split Histogram at Mean Intensity:**
   Compute the mean intensity value μ of the image.

$$\mu = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} I(i, j)$$

2. **Equalize Sub-Histograms:**
   Apply HE to pixels less than μ and those greater than or equal to μ independently.

Advantages:

- Preserves brightness.

Limitations:

- Can introduce artifacts.

6. Dualistic Sub-Image Histogram Equalization (DSIHE)

Overview:
DSIHE splits the histogram based on median intensity instead of mean.

Mathematical Process:

1. **Split Histogram at Median:**
   Find the median intensity m such that 50% of pixels are below and above this value.
2. **Equalize Sub-Histograms:**
   Apply HE independently to the two parts.

Advantages:

- Better brightness preservation.

Limitations:

- May introduce minor artifacts.

7. Dynamic Histogram Equalization (DHE)

Overview:
DHE dynamically splits the histogram into multiple parts and equalizes each to avoid over-enhancement.

Mathematical Process:

1. **Dynamic Histogram Division:**
   Divide based on intensity distribution.
2. **Equalize Each Sub-Histogram:**
   Apply HE independently to each sub-histogram.

Advantages:

- Prevents over-enhancement.

Limitations:

- Complex processing.

8. Gaussian Histogram Equalization

Overview:

This method modifies the histogram equalization process to follow a Gaussian distribution.

Mathematical Process:

1. **Gaussian Fitting:**
   Fit the cumulative distribution to a Gaussian curve.

$$G(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

2. **Intensity Mapping:**
   Map pixel values using this Gaussian distribution.

Advantages:

- Natural-looking contrast.

Limitations:

- Not suitable for non-Gaussian images.

9. Multi-Histogram Equalization (MHE)

Overview:
MHE divides the image into regions and applies HE independently to each.

Mathematical Process:

1. **Region Division:**
   Split the image into multiple regions.
2. **Regional Histogram Equalization:**
   Apply HE to each region and blend them.

Advantages:

- Enhances local contrast.

Limitations:

- Seam artifacts may occur.