Contrast Limited Adaptive Histogram Equalization

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Contrast Limited Adaptive Histogram Equalization (CLAHE) is a technique used to enhance the contrast of an image by adapting the histogram equalization process to local regions of the image. This helps to improve the visibility of details and features, especially in areas with varying illumination conditions or low contrast.

1 Histogram Equalization

The traditional histogram equalization aims to stretch the intensity distribution of an image to span the entire intensity range. Given an image I with pixel intensities ranging from 0 to $L-1$, the transformation function for histogram equalization is defined as:

$$T(r) = \frac{L-1}{N} \sum_{i=0}^{r} n_i \tag{1}$$

where N is the total number of pixels in the image, n_i is the number of pixels with intensity i, and r is the intensity level.

2 CLAHE Steps

CLAHE extends histogram equalization by applying it to small, overlapping regions called *tiles*. The steps of CLAHE are as follows:

Tile Generation

Divide the image into non-overlapping tiles of size $M \times N$.

Histogram Calculation

Calculate the histogram for each tile.

Excess Calculation

Calculate the excess histogram by subtracting a user-defined clip limit C from each bin of the histogram that exceeds C.

Excess Redistribution

Redistribute the excess from bins that exceed the clip limit to other bins within the histogram.

Cumulative Distribution Function

Compute the cumulative distribution function (CDF) of the redistributed histogram.

Scaling and Mapping

Scale the CDF to map the original pixel intensities to the enhanced intensities:

$$T_{\text{CLAHE}}(r) = \frac{L-1}{N} \sum_{i=0}^{r} n_i' \quad \text{where } n_i' \text{ is the redistributed frequency.} \tag{2}$$

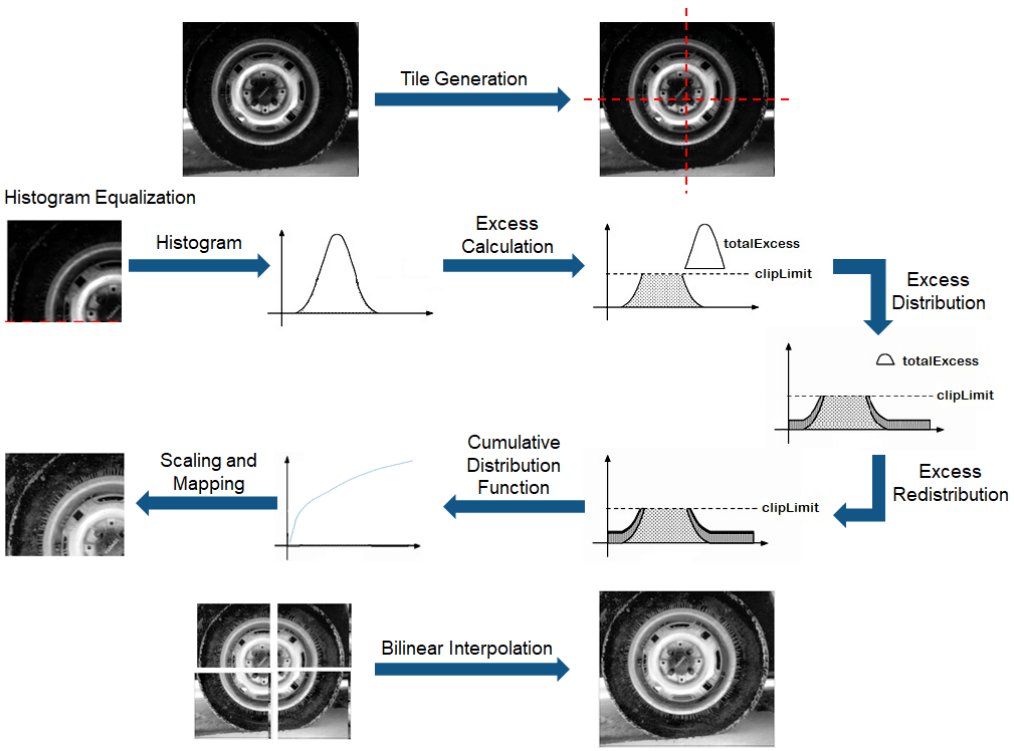

Figure 1: Contrast Limited Adaptive histogram Equalization Steps

Bilinear Interpolation

Combine the enhanced tiles using bilinear interpolation to produce the final enhanced image.

3 Results

The results can be adjusted by changing tile size and clip limit

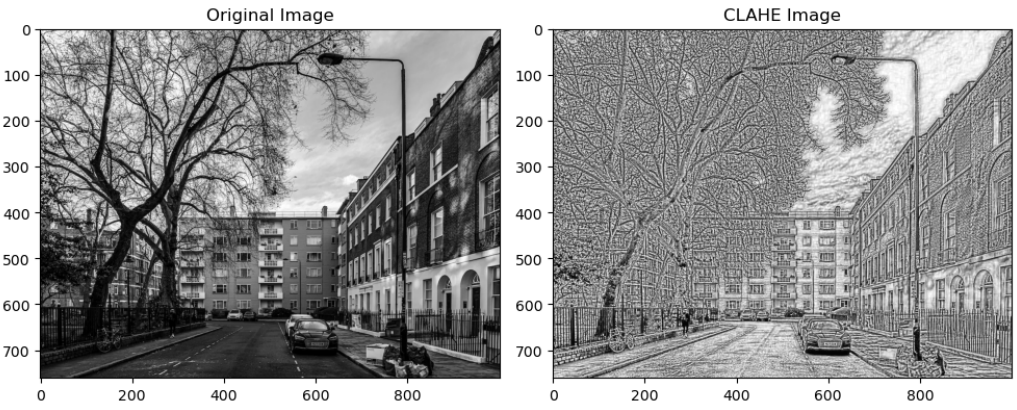

Figure 2: Input and Output Images

4 Conclusion

CLAHE improves the visibility of image details by locally equalizing histograms while considering the clip limit to avoid over-enhancement. It is particularly useful for enhancing images with non-uniform illumination and varying contrast.