Image Enhancement

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Image Enhancement

- Improve the "quality" of the image
- May be for human consumption or automated processing
- Emphasize certain aspects of the image
  - Boundary of an object
- De-emphasize certain aspects of the image
  - Noise

Image Enhancement

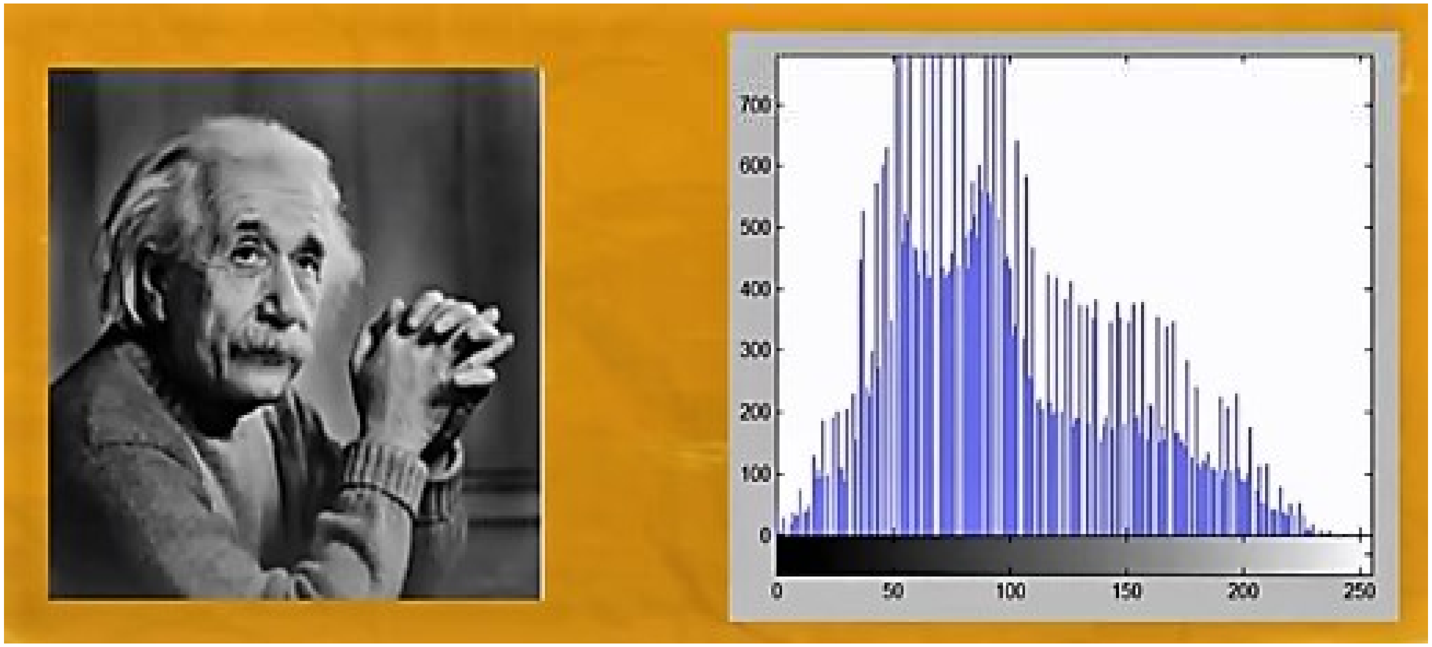
- Image to image transformation
- Many techniques
- Choice depends on the goal at hand
- Many of the tasks (i.e. images contains some structure which we want to extract) in a typical image processing program deal image enhancement

What is Histogram Equalization?

- Histogram equalization is a technique for adjusting image intensity to enhance contrast.

Cont.

- Histogram of an image can be drawn plotting pixel inten sity versus frequency of the pixel intensity or probabiliti es of pixel intensity.



Why Histogram Equalization?

- Improves contrast of image.
- Obtain uniform distribution of image intensity.

Global Histogram Equalization

- Step 1: count the total number of pixel associated with e ach pixel intensity.

- Step 2: For image with discrete gray values compute

$$p_m(r_k)=\frac{n_k}{n}, 0\le r_k \le 1, 0\le k\le L-1$$

Where L= Total number of gray levels

nk= number of pixel with gray value rk

n= total number of pixels

Cont.

- Step 3: calculate cumulative density function.

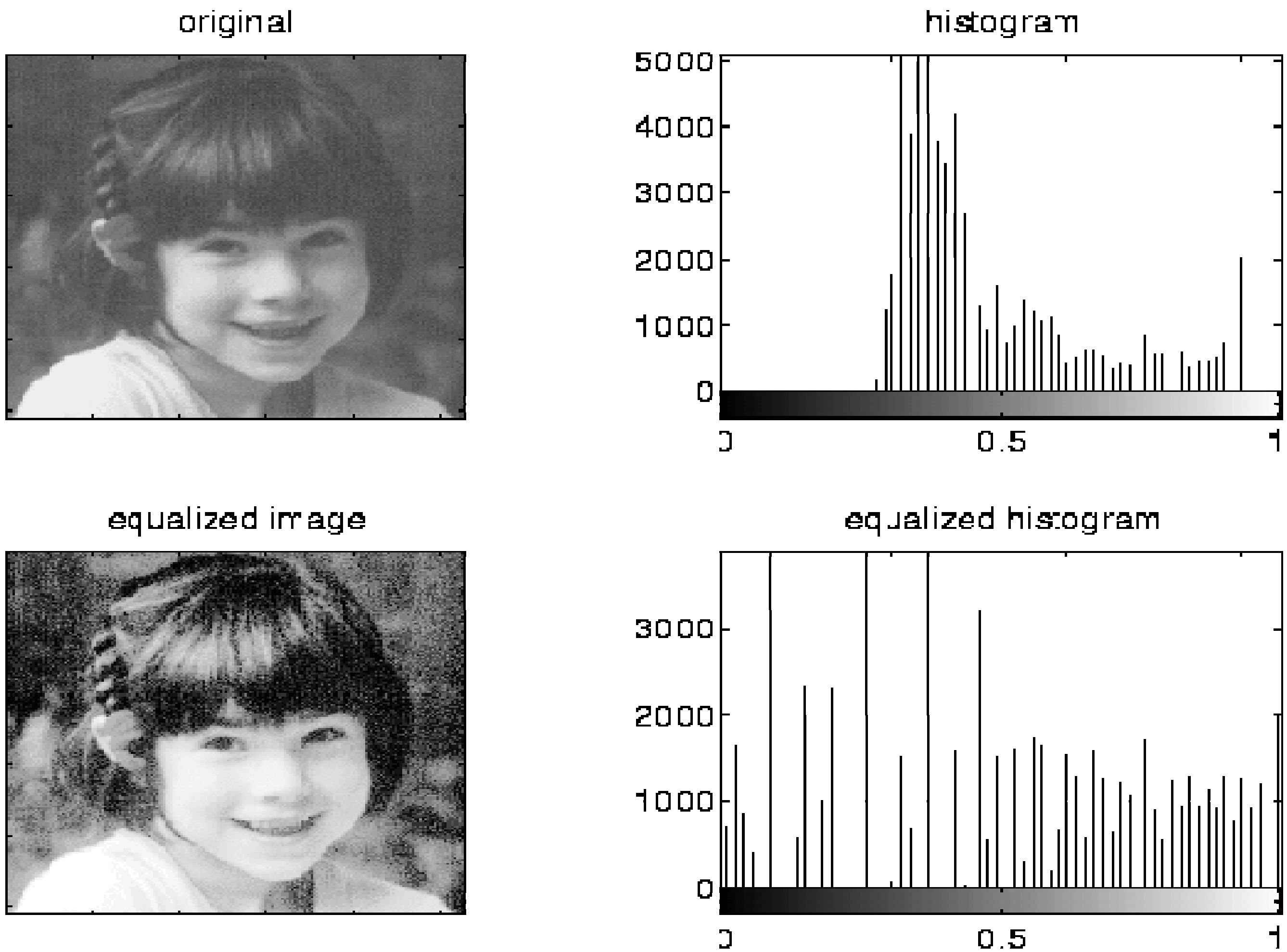
$$s_k = T(r_k) = \sum_{j=0}^{k} p_m(r_j)$$

- Step 4 : multiply cumulative probability by desired image intensity.

- Step 5 : finally round the decimal values to lower integer values known as floor rounding.

Example

- Result of Local Histogram Equalization



Implementation

- Lets take a grayscale image into matrix form.

$$\begin{bmatrix} 3 & 4 & 2 & 8 \\ 7 & 3 & 1 & 3 \\ 2 & 5 & 6 & 7 \\ 4 & 1 & 3 & 7 \end{bmatrix}$$

- The intensity vary between 1-8 . We want to change the intensity range from 1 to 20. Let's calculate the probability and cumulative probability to get the enhanc ed image.

Cont.

- Calculation :

Pixel intensity	1	2	3	4	5	6	7	8
No of pixel	2	2	4	2	1	1	3	1
Probability	0.125	0.125	0.25	0.125	0.0625	0.0625	0.1875	0.0625
Cumulative probability (C.P)	0.125	0.25	0.5	0.625	0.6875	0.75	0.9375	1
C.P * 20	2.5	5	10	12.5	13.75	15	18.75	20
Floor rounding	2	5	10	12	13	15	18	20

Cont.

- The output enhanced image is -

$$\begin{bmatrix} 10 & 12 & 5 & 20 \\ 18 & 10 & 2 & 10 \\ 5 & 13 & 15 & 18 \\ 12 & 2 & 10 & 18 \end{bmatrix}$$

Global Vs Local

- Global histogram equalization enhances the contrast of the whole image.
- Global techniques are fast and simple.
- Cannot adapt to local brightness features of the input image because only global histogram information over the whole image is used.
- Local histogram equalization enhances many image details by taking different transformation on the same gray level at different places on the whole image.

Cont.

- It is used when it is necessary to enhance details over small area in an image.

Local Histogram Equalization

- Lets consider the image –

$$\begin{bmatrix} 2 & 1 & 0 \\ 0 & 1 & 3 \\ 4 & 1 & 4 \end{bmatrix}$$

- To implement local histogram equalization we have to copy the matrix to another matrix by padding zero on all sides.

Cont.

- The resultant matrix is

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 1 & 0 & 0 \\ 0 & 0 & 1 & 3 & 0 \\ 0 & 4 & 1 & 4 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

- Now consider an window size 3*3 and starting from the position (1,1). We have to consider 9 matrix for this window size.

Cont.

- 1^{st} window is

$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 2 & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

- Find probability and cumulative probability for each pixel of this window.
- Multiply cumulative probability by 4 as no of bin is 4 and round off the value.
- Replace the middle value of the matrix with the particular round off value.

Calculation

Pixel intensity	0	1	2	3	4
No of pixel	6	2	1	0	0
probability	0.66	0.22	0.11	0	0
Cumulative probability (C.P)	0.66	0.88	0.99	0.99	0.99
C.P*4	2.64	3.56	3.96	3.96	3.96
Rounding	3	4	4	4	4

- The round off value for 2 is 4. So 2 is replaced by 4 in the matrix.
- Following same procedure we will get final matrix and the enhanced output image is -

$$\begin{bmatrix} 4 & 3 & 3 \\ 2 & 2 & 4 \\ 4 & 3 & 4 \end{bmatrix}$$

- Some global contrast enhancement techniques are:
  - Brightness preserving bi-histogram equalization (BBHE)
  - Dualistic sub-image histogram equalization (DSIHE)
  - Recursive mean separate histogram equalization (RMSHE)
  - Minimum mean brightness error bi-histogram equalization (MMBEBHE)
  - Recursive separated and weighted histogram equalization (RSWHE)

BBHE

- Decomposed input image into two sub-images on basis of mean value.
- One sub-image contains the set of samples that are less than or equal to mean.
- Other sub-image is the set of samples greater than mean.
- Equalizes both sub images independently according to their respective histograms.

Ref: Review of Different Local and Global Contrast Enhancement Techniques for a Digital Image.

- Resultant equalized sub images are bounded by each other around input mean, which has an effect of preserving the mean brightness.

- Advantage:

  Preserves mean brightness of the image while enhanc ing the contrast and provides much natural enhancement.

Cont.

Original image

Image after BBHE

- Let Im be the mean of the image X and assume that Im ∈ {0, L-1}. Based on Im , the image separated into two sub-images Xl and Xu.
- Respective PDF –

$$p_L(X_k) = \frac{n_L^k}{n_L}$$

$$p_U(X_k) = \frac{n_U^k}{n_U}$$

- Respective CDF –

$$c_L(x) = \sum_{j=0}^{k} p_L(X_j)$$

$$c_U(x) = \sum_{j=m+1}^{k} p_U(X_j)$$

- Transform function –

$$f_L(x) = X_0 + (X_m - X_0)c_L(x)$$

$$f_U(x) = X_{m+1} + (X_{L+1} - X_{m+1})c_U(x)$$

- Output image of BBHE –

$$
\begin{aligned}
\mathbf{Y} &= \{Y\{i, j)\} \\
&= f_L(\mathbf{X}_L) \cup f_U(\mathbf{X}_U)
\end{aligned}
$$

DSIHE

- Decomposes an image into two equal area sub-images based on its probability density function.
- Two sub-images are equalized respectively and get resul t after composing two image into one image.
- It can not only enhance image information effectively but also keep the luminance well enough so that it can be used in video system directly.

- Ref : *Image enhancement based on equal area dualistic sub-image histogram equalization method*

- Image X is segmented by a section with gray level of X=Xe and the two sub-images are Xl and Xu so we have X=Xl U Xu.
- corresponding cumulative distribution function for Xl and Xu will be

$$C_L(X_K) = \frac{1}{P}\sum_{i=0}^{k} P_i$$

$$C_U(X_K) = \frac{1}{1-P}\sum_{i=e}^{l-1} P_i$$

- Transform function of two sub-images are

$$Y = f_L(X_K) \cup f_U(X_U)$$

$$f_U(X_K) = X_e + (X_{l-1} - X_e) C_U(X_K)$$

- Result of the dualistic sub-image histogram equalization is obtained after the two equalized sub-images are composed into one image-

$$Y = f_L(X_K) \cup f_U(X_U)$$

Example

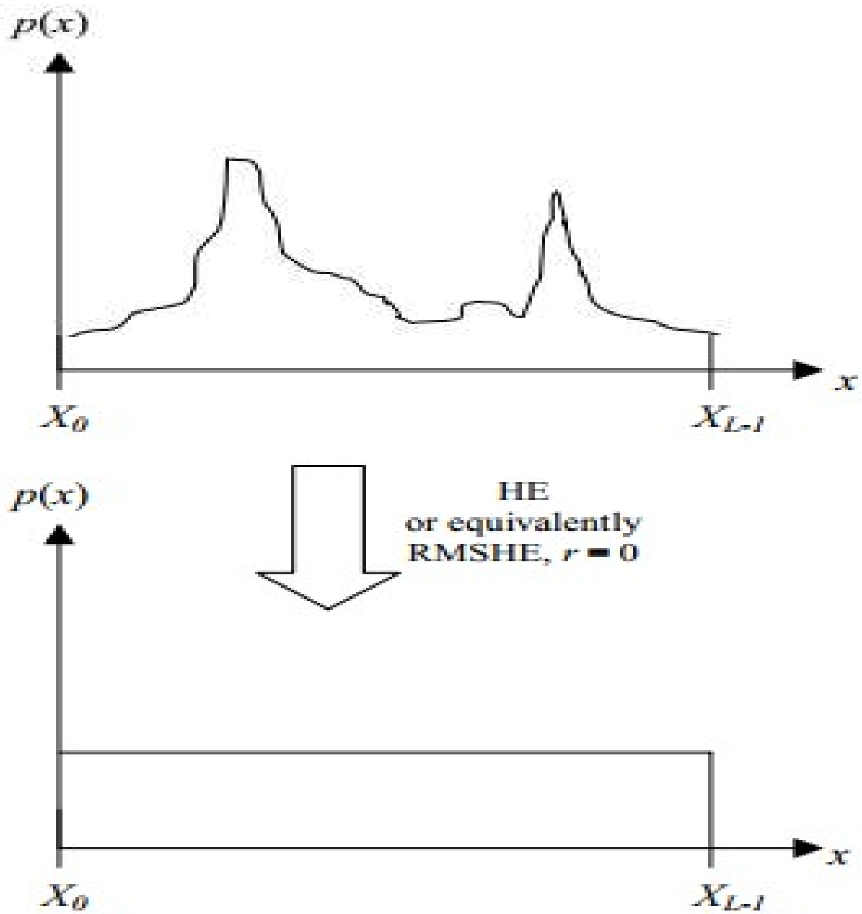
- Original image

- Image after DSIHE

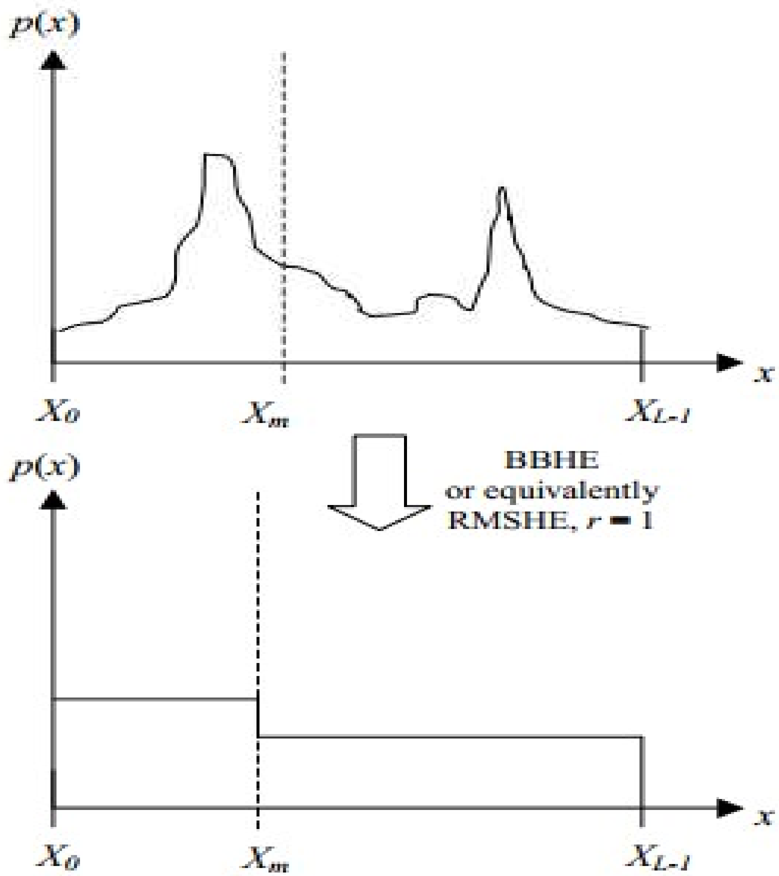
RMSHE

- RMSHE is a generalization of HE and BBHE in terms of brightness preservation.
- Separates input image into two sub-images based on its mean and perform the separation recursively.
- Separate each new histogram further based on their respective mean.
- Output mean will converge to the input mean as the number of recursive mean-separation increases.
- RMSHE allows scalable brightness preservation, which is very useful in consumer electronics.

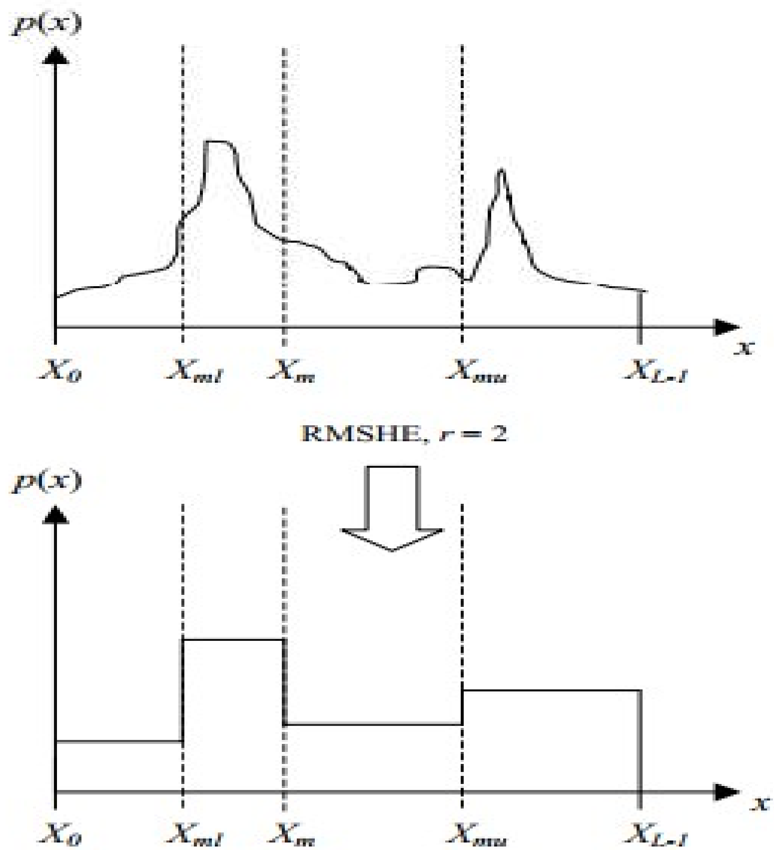
- HE is equivalent to RMSHE with recursion level, r = 0.



- BBHE is equivalent to RMSHE with recursion level r = 1.



- Input image X is further separated into 4 portions based on the mean of the two new histograms Xml and Xmu.



- Xml and Xmu are defined as –

$$X_{ml} = \frac{\int_{X_0}^{X_m} xp(x)dx}{\int_{X_0}^{X_m} p(x)dx} = 2\int_{X_0}^{X_m} xp(x)dx$$

$$X_{mu} = \frac{\int_{X_m}^{X_{L-1}} xp(x)dx}{\int_{X_m}^{X_{L-1}} p(x)dx} = 2\int_{X_m}^{X_{L-1}} xp(x)dx$$

$$\int_{X_0}^{X_m} p(x)dx = \int_{X_m}^{X_{L-1}} p(x)dx = \frac{1}{2}$$

- The formulation of the output mean is given as –

$$
\begin{aligned}
E(\mathbf{Y}) = & E(\mathbf{Y} \mid \mathbf{X} \le X_{ml}) Pr(\mathbf{X} \le X_m) \\
& + E(\mathbf{Y} \mid X_{ml} < \mathbf{X} \le X_m) Pr(X_{ml} < \mathbf{X} \le X_m) \\
& + E(\mathbf{Y} \mid X_m < \mathbf{X} \le X_{mu}) Pr(X_m < \mathbf{X} \le X_{mu})
\end{aligned}
$$

- Ref : *Contrast Enhancement using Recursive Mean-Sepa rate Histogram Equalization for Scalable Brightness Pre servation*

Example

- Original image

- Image after RMSHE with r=2

MMBEBHE

- It is based on the principle of Brightness Preserving Bi-Histogram Equalization (BBHE) and Dualistic Sub-imag e Histogram Equalization (DSIHE).
- Decomposes input image into two sub-images in such a way that the minimum brightness difference between input image and output image is achieved.
- It is called absolute mean brightness error (AMBE)
- After decomposing input image by the threshold level, each of the two sub-images undergo histogram equalization process to generate the output image.

RSWHE

- RSWHE is designed to achieve two goals: preserve the image brightness and enhance the image contrast.
- It first modifies the input histogram and then runs the equalization procedure.
- It is composed of three basic modules: histogram segmentation module, histogram weighting module and histogram equalization module.

- Histogram segmentation module:

  Split an input histogram into two or more sub-histogram recursively based on the mean or median of the image.

- Histogram weighting module:

  Modifies sub-histograms through a weighting process based on a normalized power law function.

- Histogram equalization module:

  Equalizes the weighted sub-histograms independently.

- Ref: *Recursively Separated and Weighted Histogram Equalization for Brightness Preservation and Contrast Enhancement.*

- Result of RSWHE : RSWHE-M is the best method for brightness preservation and contrast enhancement and RSWHE-D is the second best method.

RSWHE-M (r =2)

RSWHE-D (r =2)

- Some local enhancement technique are –

- Adaptive histogram equalization (AHE)

- Contrast limited adaptive histogram equalization (CLAHE)

- Ref : *Intensity Transformation using Contrast Limited Adaptive Histogram Equalization*

AHE

- Intensities are distributed locally and contrast is enhanced based on the local area rather than the entire image .
- Computes several histograms, each corresponding to a distinct section of the image.
- Use histograms to redistribute the lightness values of the image.
- The resultant image is produced where each pixel is mapped differently.
- AHE has a tendency to over amplify noise in relatively homogeneous regions of an image.

Implementation

Fig. 6(a). Original image

Fig. 6(b). AHE image

CLAHE

- Prevents the over amplification of noise that adaptive histogram equalization can give rise to.
- 1. Obtain all the inputs of image.
- 2. Determine real clip limit from the normalized value if necessary, pad the image before splitting it into regions.
- 3. Extract a single image region, make a histogram for this region using the specified number of bins, clip the hi stogram using clip limit, create a mapping.
- 4. Extract a single pixel, apply four mappings to that pix el and interpolate between the results to obtain the outpu t pixel; repeat over the entire image.

Implementation

Fig. 7(a). Original image Fig. 7(b). CLAHE image