

There are various types of *image fusion* such as fusion of images of different spatial resolution, fusion of images from different types, fusion of information extracted from images of various sources. Fusion of images can be achieved in a number of ways including the use of principal component analysis and wavelet transform among other approaches. The goal is to make integrated use of spatial and spectral data from multiple sources (Gong, 1994). For remote sensing of human settlements, deriving texture and other spatial features from images are important components of image enhancement. In this section, we will introduce the principles of histogram adjustment, morphological filtering, Gram-Schmidt orthogonalization, texture feature generation, and image fusion (see Figure 4-2).

4.4.1 Histogram Adjustment

The most straightforward histogram matching is *histogram equalization* that transforms a histogram of any shape to a histogram with the same frequency along the whole range of digital numbers (DN) (Figure 4-12).

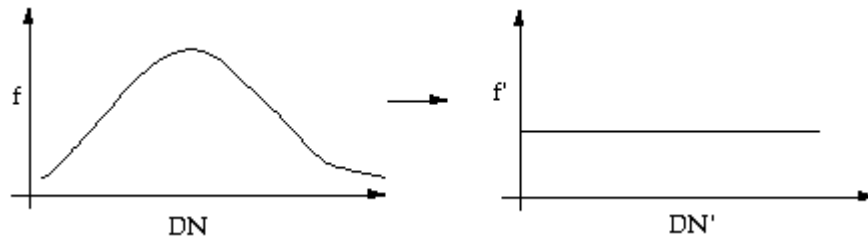


Figure 4-14. In the continuous case, equalizing the left histogram (f) to the one on the right (f') by reshaping f . [B/W]

The equalization process can be realized through histogram matching (Horn and Woodham, 1979). The cumulative histogram F_{c1} of the original image is matched to the new cumulative histogram F_{c2} (Figure 4-15).

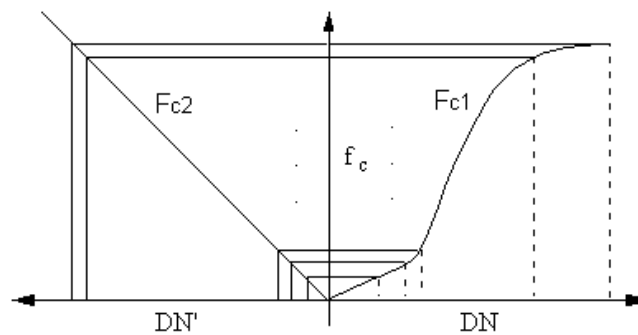


Figure 4-15 Matching the cumulative histogram on the right F_{c1} to the F_{c2} on the left. Any greylevels from the right (DN) whose cumulative histogram corresponds to a greylevel on the left (DN') will be assigned as DN'. [B/W]

The following example shows how an equalization made in discrete digital form through histogram matching (Table 4-2) with a 3-bit image (only 2^3 , 8 gray levels). It starts with the generation of image histogram (first two columns in Table X). Then probability, P_i is calculated from frequency, $f(v_i)$ (third column). A cumulative histogram F_c can be calculated from frequencies. Similarly, the cumulative distribution function (CDF) can be derived from probabilities. Based on the cumulative distribution function we can convert the original gray levels into gray levels of the equalized image.

The assumption for histogram matching is that each detector (sensor) has the same probability of seeing the scene and, therefore, the gray-level distribution function should be the same. Thus if two detectors have different histograms (a discrete version of gray-level distribution function), they should be corrected to have the same histogram. Figure 4-16 shows two histograms to be matched.

Table 4-2 Histogram, Cumulative Histogram, Cumulative Distribution Function (CDF), and the Output in Histogram Equalization

Grey Level DN	Frequency $f(v_i)$	Probability P_i	Cumulative histogram F_c	CDF	$(2^3 - 1) * CDF$	Output DN' (Round off)
0	4	0.04	4	0.04	0.28	0
1	17	0.17	21	0.21	1.47	1
2	15	0.15	36	0.36	2.52	3
3	18	0.18	54	0.54	3.78	4
4	24	0.24	78	0.78	4.46	4
5	12	0.12	90	0.90	6.3	6
6	0	0	90	0.90	6.3	6
7	10	0.10	100	1.00	7	7
	100	1.00				

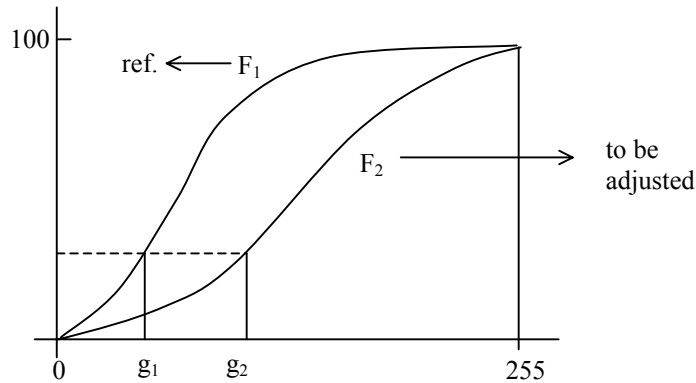


Figure 4-16. Matching the histogram F2 to the reference histogram F1. [B/W]

This process is done for each given gray-level, g_2 , to find its cumulative frequencies $fc_2(g_2)$ in F2. Then in F1 find the gray-level value, g_1 , such that its cumulative frequency $fc_1(g_1) = fc_2(g_2)$. Then assign g_1 to g_2 in the histogram to be adjusted. Histogram matching can be used to balance detector responses as a relative detector calibration technique. In image mosaicking, when the overlapped images are different in radiometry, it can be used to balance the differences. When two images acquired by the same sensor over the same location but at different times and atmospheric conditions, it can be used to normalize the two images.

Histogram equalization and histogram matching

Digital numbers below are randomly generated to simulate two 4-bit image scenes of 10 by 10 pixels. The digital numbers range from 0 to 15.

1. Two images

a. An image to be adjusted

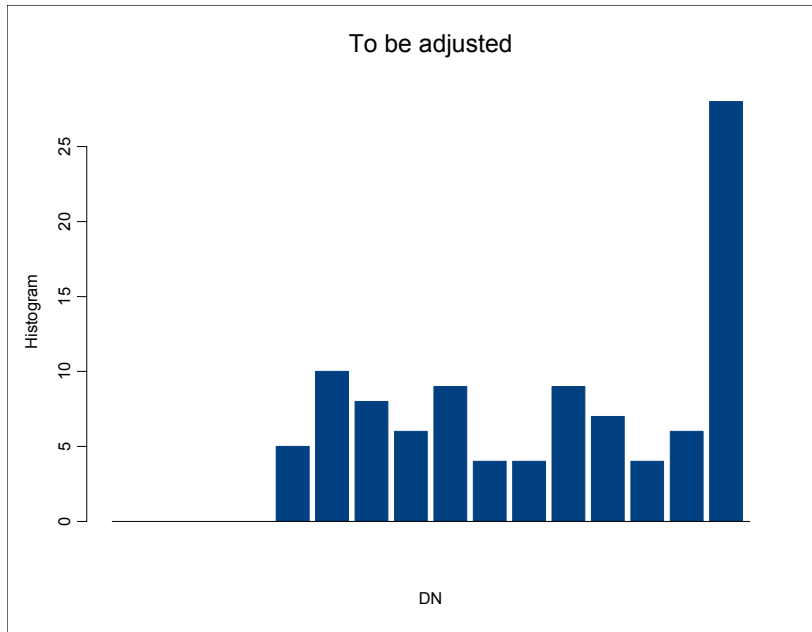
	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]	[,9]	[,10]
[1,]	10	8	15	14	7	11	15	11	15	15
[2,]	14	13	15	5	6	15	4	11	10	15
[3,]	13	6	15	13	12	9	12	15	5	15
[4,]	5	15	15	15	13	15	11	7	14	6
[5,]	15	9	7	4	8	7	7	11	4	15
[6,]	4	12	15	11	8	12	5	5	8	5
[7,]	15	12	9	15	14	6	6	14	11	15
[8,]	12	5	5	8	11	6	4	5	15	15
[9,]	10	11	8	15	9	15	14	8	15	10
[10,]	6	15	7	12	15	8	6	8	5	15

b. A reference image

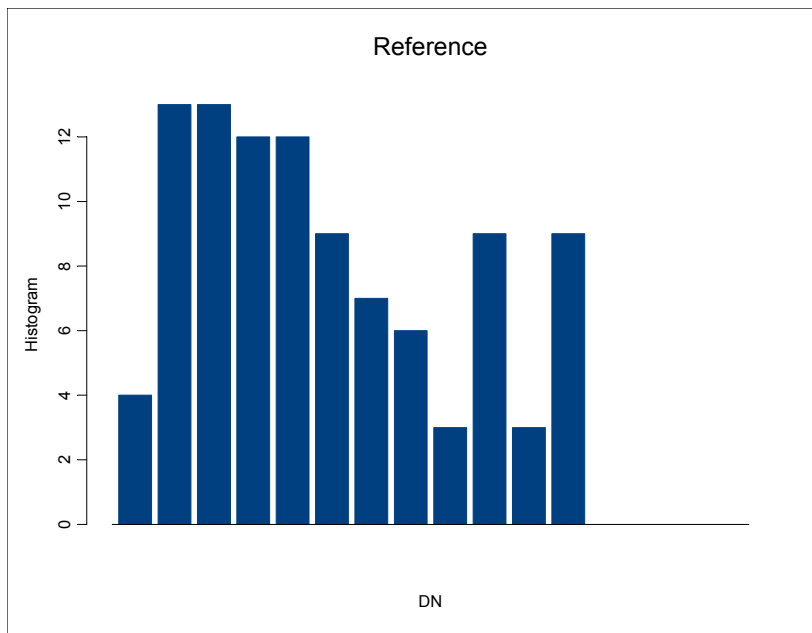
	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]	[,9]	[,10]
[1,]	5	1	1	7	5	3	1	2	8	6
[2,]	11	6	4	4	2	6	4	1	4	9
[3,]	0	3	11	1	0	1	3	2	4	10
[4,]	9	3	5	7	9	11	3	11	2	2
[5,]	3	5	1	8	9	11	3	9	11	2
[6,]	5	3	4	0	2	4	7	7	11	3
[7,]	1	9	11	9	2	5	2	4	4	5
[8,]	6	6	2	0	11	3	5	3	9	4
[9,]	6	1	2	1	10	1	2	4	5	6
[10,]	7	2	1	4	1	3	9	7	10	8

2. Two histograms

a. Histogram of the image to be adjusted

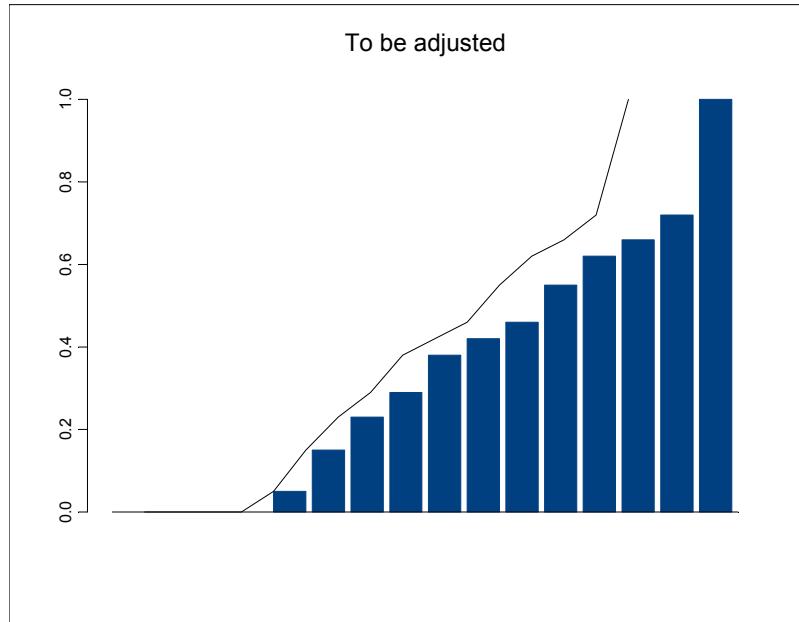


b. Histogram of the reference image

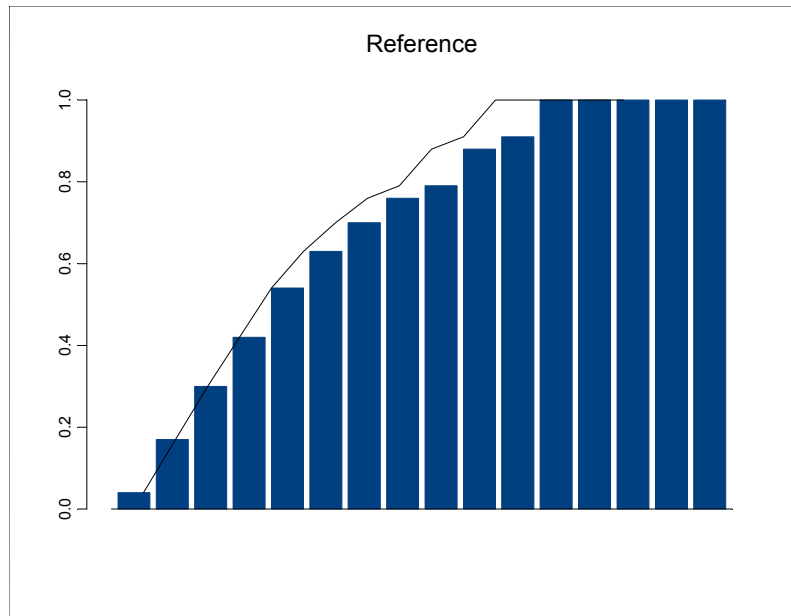


3. Two cumulative histograms

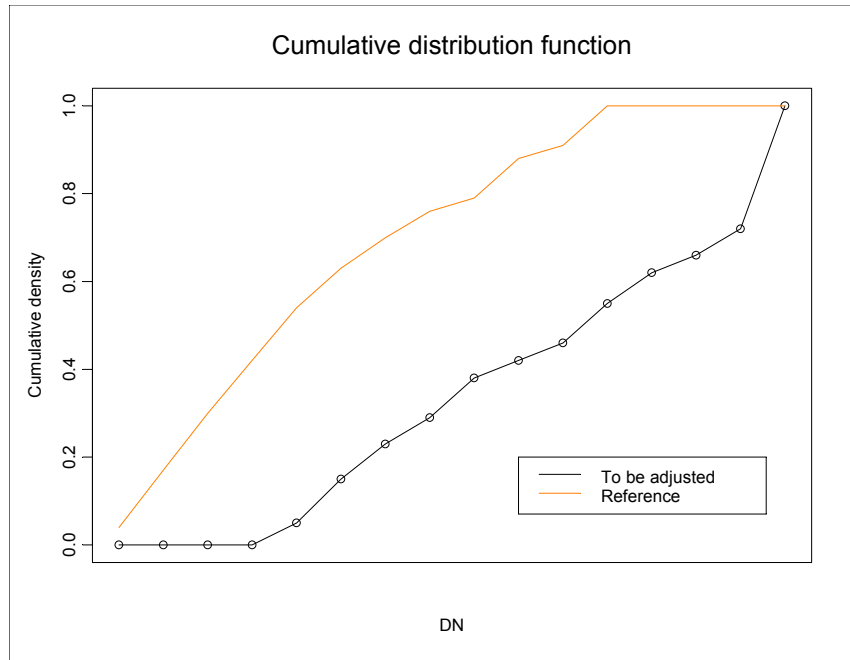
a. Cumulative distribution function of the image to be adjusted



b. Cumulative distribution function of the reference image



c. Two cumulative distribution functions



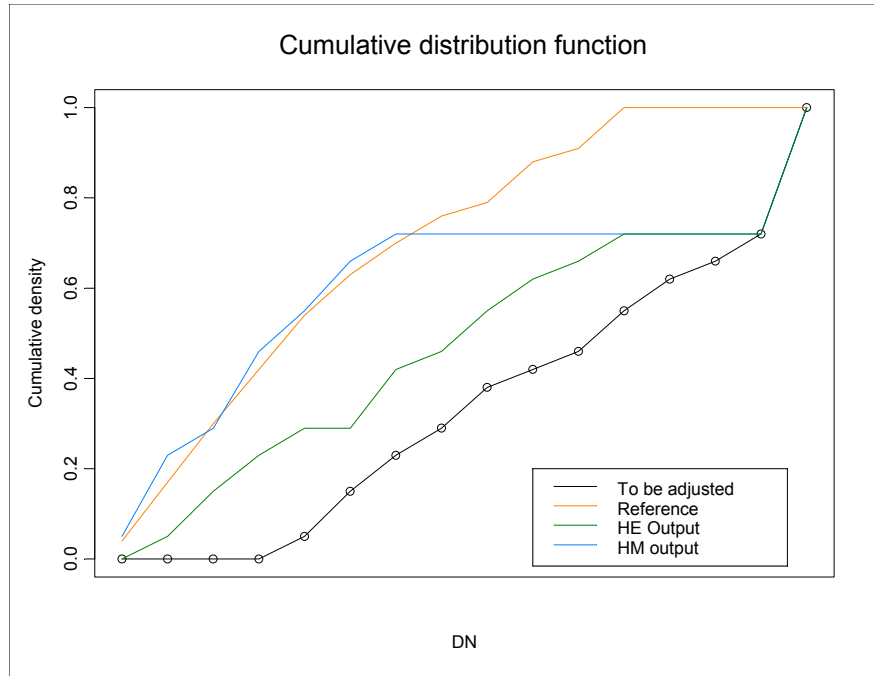
4. Results

- a. Tabulate DN, CDFs of the two images, and results of histogram equalization and histogram matching

DN		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CDF	Adjusted	0	0	0	0.05	0.15	0.23	0.29	0.38	0.42	0.46	0.55	0.62	0.66	0.72	1	
	Reference	0.04	0.17	0.30	0.42	0.54	0.63	0.70	0.76	0.79	0.88	0.91	1	1	1	1	1
Hist Equal		0	0	0	0	1	2	3	4	6	6	7	8	9	10	11	15
Hist Match		0	0	0	0	0	1	1	2	3	3	3	4	5	5	6	15

The result of histogram equalization is obtained by rounding off $15 \cdot \text{CDF}$ (to be adjusted). The output of histogram matching is obtained by finding the DN that the adjusted image has the same cumulative density as the reference image. Practically it is to look for the DN that has the closest CDF matching of the adjusted image to the reference image.

- b. Output cumulative distributions of histogram equalization (dark green curve) and histogram matching (blue curve)



c. DN outputs of histogram equalization and histogram matching

HE	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]	[,9]	[,10]
[1,]	7	6	15	11	4	8	15	8	15	15
[2,]	11	10	15	2	3	15	1	8	7	15
[3,]	10	3	15	10	9	6	9	15	2	15
[4,]	2	15	15	15	10	15	8	4	11	3
[5,]	15	6	4	1	6	4	4	8	1	15
[6,]	1	9	15	8	6	9	2	2	6	2
[7,]	15	9	6	15	11	3	3	11	8	15
[8,]	9	2	2	6	8	3	1	2	15	15
[9,]	7	8	6	15	6	15	11	6	15	7
[10,]	3	15	4	9	15	6	3	6	2	15

HM	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]	[,9]	[,10]
[1,]	3	3	15	6	2	4	15	4	15	15
[2,]	6	5	15	1	1	15	0	4	3	15
[3,]	5	1	15	5	5	3	5	15	1	15
[4,]	1	15	15	15	5	15	4	2	6	1
[5,]	15	3	2	0	3	2	2	4	0	15
[6,]	0	5	15	4	3	5	1	1	3	1
[7,]	15	5	3	15	6	1	1	6	4	15
[8,]	5	1	1	3	4	1	0	1	15	15
[9,]	3	4	3	15	3	15	6	3	15	3
[10,]	1	15	2	5	15	3	1	3	1	15