Chapter 9
Gray-Level Transformation

The visual appearance of an image is generally characterized by two properties: *brightness* and *contrast*. Brightness refers to the overall intensity level and is therefore influenced by the individual gray-level (intensity) values of all the pixels within an image. Since a bright image (or subimage) has more pixel gray-level values closer to the higher end of the intensity scale, it is likely to have a higher average intensity value. Contrast in an image is indicated by the ability of the observer to distinguish separate neighboring parts within an image. This ability to see small details around an individual pixel and larger variations within a neighborhood is provided by the spatial intensity variations of adjacent pixels, between two neighboring subimages, or within the entire image. Thus, an image may be bright (due to, for example, overexposure or too much illumination) with poor contrast if the individual target objects in the image have optical characteristics similar to the background. At the other end of the scale, a dark image may have high contrast if the background is significantly different from the individual objects within the image, or if separate areas within the image have very different reflectance properties.

The definition of contrast can be extended from illumination to image pixel intensity (Sec. 2.5). For a captured image with maximum and minimum gray-level values $g_{\max}$ and $g_{\min}$, and using the sinusoidal image intensity shown in Fig. 9.1, image contrast modulation and mean brightness are given by

$$\text{contrast modulation} = \left[\frac{g_{\max} - g_{\min}}{g_{\max} + g_{\min}}\right] \tag{9.1a}$$

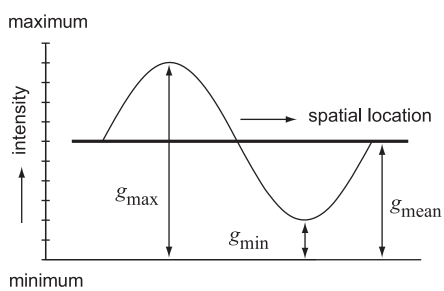

Figure 9.1 Conceptual sinusoidal intensity line profile along the horizontal axis.

and

$$\text{mean brightness} = \left[\frac{g_{\max} + g_{\min}}{2}\right]. \tag{9.1b}$$

An alternate quantification contrast used in the literature is contrast ratio = $g_{\max}/g_{\min}$.

Although the intensity distribution within any real-life image is unlikely to be purely sinusoidal, these definitions provide a basis for comparison. For example, an image that contains pixels with brightness values spread over the entire intensity scale is likely to have better contrast than the image with pixel gray-level values located within a narrow range. This relationship between the intensity spread at the pixel level and the overall appearance of an image provides the basis for image enhancement by gray-level transformation. This chapter describes some of the commonly used mapping rules used in preprocessing operations. The notational conventions used in this chapter are $N_x \times N_y$ = image size, (i, j) = pixel location, $\{g_{in}(i, j)\}_{N_x \times N_y}$ = collection of input (source) image pixel gray-level intensities, $\{g_{out}(i, j)\}_{N_x \times N_y}$ = collection of output image pixel gray-level intensities, and $(0, G)$ = full-scale intensity resolution of the source image.

9.1 Pixel-to-Pixel Mapping

Since the spatial variation of brightness over an image has a significant influence on its visual appearance, a very basic form of image enhancement can be achieved by changing the intensity values of the neighboring pixels. The simplest means of increasing (or decreasing) brightness is to add a constant value to (or subtract from) all gray-level values or multiply (divide) all gray values by a constant number. These computations can be combined to form one of the following arithmetic operations on the intensity values in the input image pixels:

$$g_{out}(i, j) = k_1 g_{in}(i, j) + b_1 \quad \text{or} \quad g_{out}(i, j) = k[g_{in}(i, j) + b], \tag{9.2a}$$

where k_1, k, and b_1, b are user-defined gain and bias parameters. To contain the output gray values within a user-specified intensity range $(0, A \leq G)$, it is more appropriate to modify the above input-output relation to the form

$$g_{out}(i, j) = [A/g_{\max} - g_{\min}]\{g_{in}(i, j) - g_{\min}\}, \tag{9.2b}$$

which gives $k = A/(g_{\max} - g_{\min})$ and $b = -Ag_{\min}/(g_{\max} - g_{\min})$. A major limitation of Eq. (9.2) is that it is linear, i.e., all gray values in the input image are subjected to the same gain or bias parameters. The terms *gray value* and *intensity* are used synonymously to describe pixel brightness. While it is possible to formulate a nonlinear analytical mapping, a more convenient form of defining an application-specific intensity transformation is a stored *look-up table*. Other than its numerical convenience, a look-up table can create an arbitrary input-output map subject only

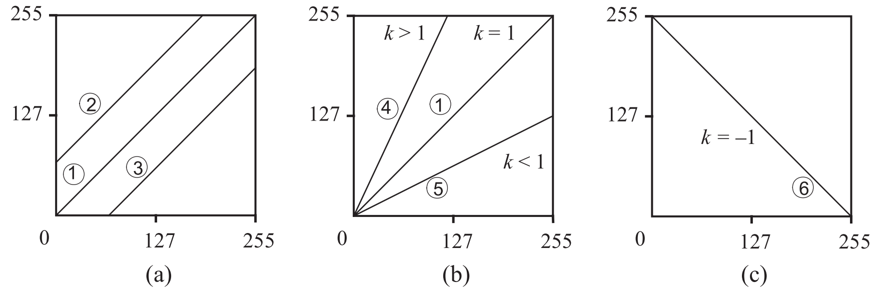

Figure 9.2 Commonly used look-up tables. (a) Biasing or intensity sliding, where 1 means that the output intensity is the same as the input intensity (do nothing), 2 means increased brightness (sliding up, positive bias value b), and 3 means reduced intensity (sliding down, negative bias value b). (b) Scaling or intensity stretching, where 4 means expanded brightness separation (scaling up, $k > 1$), and 5 means reduced brightness separation (scaling down, $k < 1$). (c) Intensity inversion: $g_{out}(i, j) = G - g_{in}(i, j)$ (6 corresponds to the inversion of 1).

to one constraint: that its entries be integer values within the permissible intensity range. The input-output maps generated by Eq. (9.2) as continuous-function look-up tables are shown in Fig. 9.2, and their effects are highlighted in Fig. 9.3.

9.2 Gamma Correction[1]

In conventional photographic film, the incident light (illumination) is converted to the optical density, which appears as image brightness. Although an unexposed film is expected to be totally dark when developed, there is generally a baseline brightness referred to as the *film base + fog*. Although fog goes up with exposure time, base+fog is typically taken to be up to 10% of the full density scale. The linear part of the optical transformation curve in Fig. 9.4 starts off at this level with an exponential shape at the base+fog level (*toe*), then becomes linear and slows down nearer the top of the density scale (*shoulder*) with a logarithmic slope before reaching its saturation limit. In the photographic literature, the gradient of the slope of this *Hurter and Driffield (H&D) curve* is referred to as gamma (γ).

A similar input-output mapping is embedded in CRT displays. The luminance output is related to the grid voltage V_{grid} with a power rule of the form

$$L_{display} = \alpha V_{grid}^{\gamma}, \tag{9.3a}$$

where α controls the brightness setting, and γ adjusts the contrast level. Most CRT devices provide two control knobs to adjust these two viewing parameters. The standard values of γ are 2 in the NTSC standard and 2.7 in PAL. For RGB monitors, figures in the range of 1.4 to 2.78 are quoted in the literature.[1]

In the imaging context, *gamma correction* refers to a preprocessing operation that compensates for the above power relation. In the basic form of gamma correction, an *inverse power* relation of the form

$$g_{\gamma out}(i, j) = [g_{in}(i, j)]^{\frac{1}{\gamma}} \tag{9.3b}$$

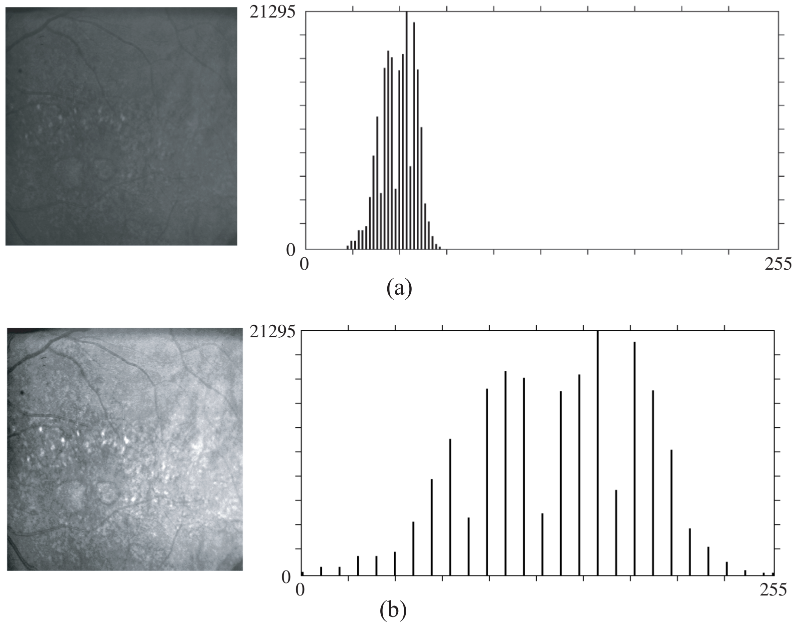

Figure 9.3 Intensity stretching and bias using a 256-gray-level image. (a) Input image and histogram (Sec. 9.3). (b) Output image and histogram for $b = -22,\ k = 5$ (courtesy of Data Translation, Basingstoke, UK and Marlboro, MA).

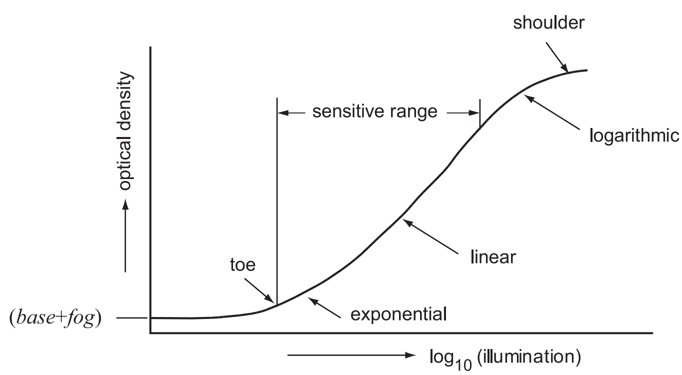

Figure 9.4 H&D curve modeling photographic film exposure characteristics, where $\gamma > 1$ is in the toe region, $\gamma < 1$ is in the shoulder region, and $\gamma \simeq 1$ is in the linear portion[1] (b = base and f = fog). In the image sensor literature, the $(b + f)$ range is referred to as the *dark current* level (or the *noise floor*), and the optical density range over the linear portion is the *dynamic range*. The sensor output trails off after reaching the peak at the shoulder area. The replacement of density with brightness B and illumination with exposure H yields the photographic tone reproduction (*tone-scale curve*) $B = a \log H + b$, where a is the contrast (gamma) and b is the exposure or film speed. Tone-scale curves are used to assess visual perception and to monitor luminance.

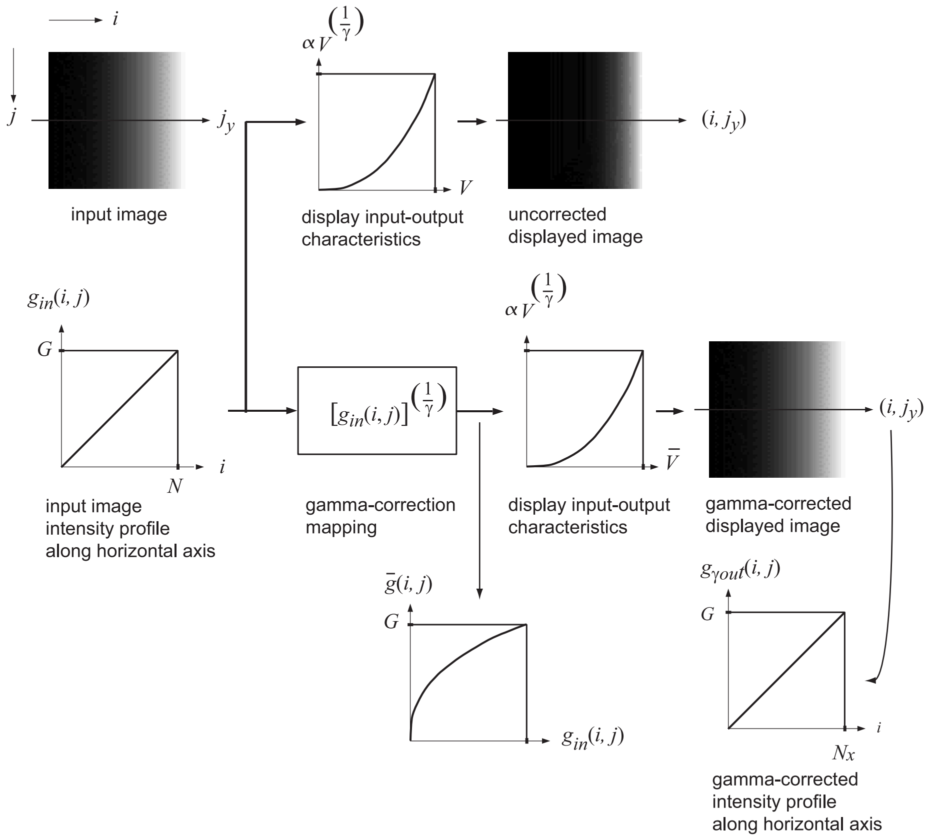

Figure 9.5 Illustration of an image with and without gamma correction. The source image is generated from a ramp intensity profile with 256 intensity levels (simulated results with $\alpha = 1$ and $\gamma = 2$).

is used to condition the source image intensity value. This preprocessed image signal is then fed into the CRT display to create a linear relationship between the source signal and its displayed luminance value. The default values of γ are as given above, but the required level of gamma correction may be subjective and related to the intensity range and distribution of the input image. For $0 < \gamma < 1$, the above equation (exponential curve, toe) darkens the output image; for $\gamma > 1$ (logarithmic curve, shoulder), the image becomes brighter. For illustration, the visual effects of gamma corrections are shown in Fig. 9.5. The shapes are of a selection of gamma curves given in Fig. 6.5(c) (Sec. 6.1).

9.3 Image Histogram

A histogram provides a pictorial description of the distribution of a large set of data (population) in terms of the *frequency of occurrence* of each characteristic feature (variate) of the population member. Some of the definitions and related properties are summarized in Appendix 9A at the end of this chapter. By using