Chapter 9

Image Enhancement Processing

9.1 Image Processing in the Imaging Chain

The output of the digital sensor is a “raw” digital image that consists of an array of digital count values with each value representing the brightness, or gray level, of a pixel in the image. Image processing is generally employed in the imaging chain to improve the efficacy of the image data (Fig. 9.1). Although image processing is a very broad field that includes compression, feature detection, and classification,[1,2] we will focus our discussion here on the common processing methods used to enhance the visual quality of the image. Specifically, we will first look at contrast enhancement methods, and then at spatial filtering methods that sharpen edges and remove much of the image blur. (Detector calibration is usually the first step of the image enhancement chain, but this was discussed earlier as part of the sensor modeling.) For simplicity, we will assume that the images have an eight-bit dynamic range; i.e., there are $2^8 = 256$ possible gray levels, so the gray levels in the image will be in the range 0–255, with zero being black and 255 being white. Color images have three arrays of numbers typically representing the red, green, and blue images that are combined to give the full spectrum of colors. We will focus on processing single-band images, i.e., black and white images.

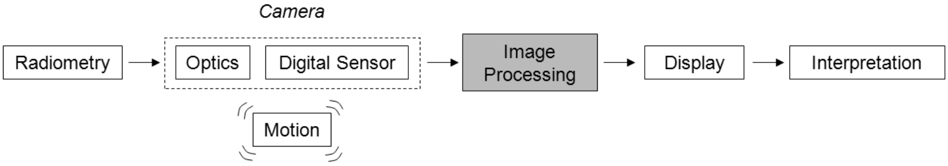

Figure 9.1 Modeling the image processing is important in understanding the camera’s full potential image quality.

9.2 Contrast Enhancements

Contrast enhancements improve the perceptibility of objects in the scene by enhancing the brightness difference between objects and their backgrounds. Contrast enhancements are typically performed as a contrast stretch followed by a tonal enhancement, although these could both be performed in one step. A contrast stretch improves the brightness differences uniformly across the dynamic range of the image, whereas tonal enhancements improve the brightness differences in the shadow (dark), midtone (grays), or highlight (bright) regions at the expense of the brightness differences in the other regions.

9.2.1 Gray-level histogram

Most contrast enhancement methods make use of the gray-level histogram, created by counting the number of times each gray-level value occurs in the image, then dividing by the total number of pixels in the image to create a distribution of the percentage of each gray level in the image (Fig. 9.2). The gray-level histogram describes the statistical distribution of the gray levels in the image but contains no spatial information about the image. Figure 9.3 illustrates the characteristics of a gray-level histogram for bright and dark scenes as well as for high- and low-contrast scenes. Setting the exposure of the camera to span the full dynamic range would optimize the contrast, but this runs the risk of saturating the detector with any radiance value that would exceed 255 counts, thus clipping these values into 255 counts and losing any scene information above this radiance level. Exposures are, therefore, usually set to collect lower-contrast images that do not span the dynamic range because the images can be processed later to enhance the contrast while maintaining control over the amount of clipping that occurs.

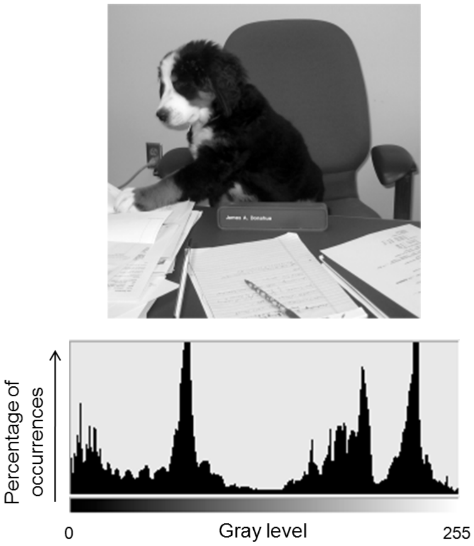

Figure 9.2 The gray-level histogram for an image.

Contrast enhancement processes adjust the relative brightness and darkness of objects in the scene to improve their visibility. The contrast and tone of the image can be changed by mapping the gray levels in the image to new values through a gray-level transform. The mapping function reassigns the current gray level *GL* to a new gray level *GL'* (Fig. 9.4).

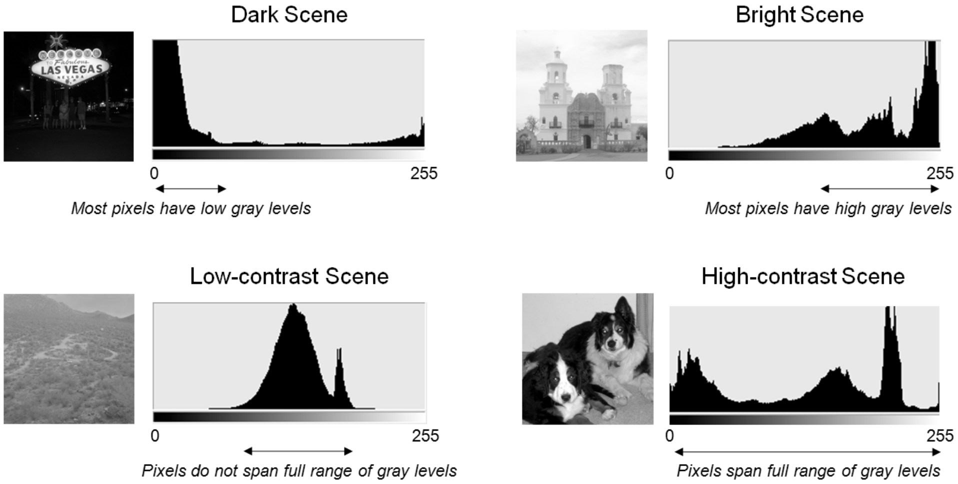

Figure 9.3 The gray-level histogram for different brightness and contrast scenes.

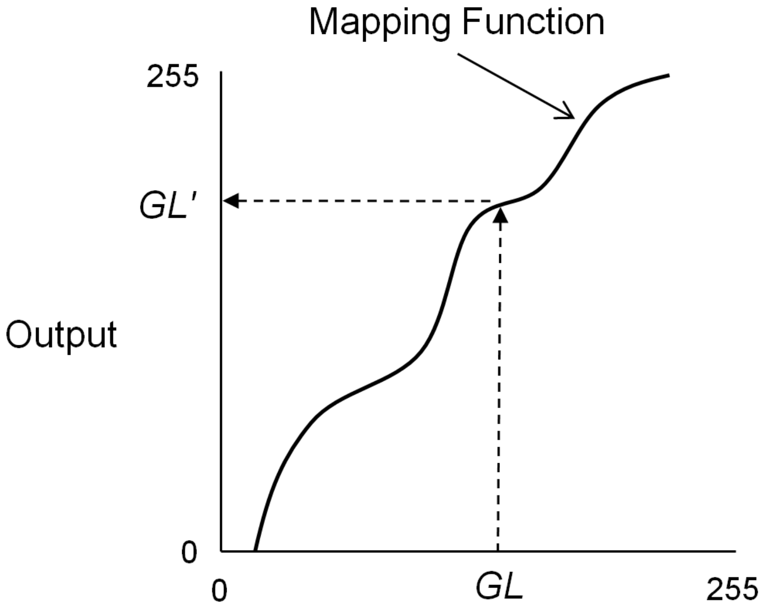

Figure 9.4 A gray-level transform maps the gray levels to new values.

Perhaps the simplest example of a gray-level transform is contrast reversal, in which a new image $g'(x, y)$ is created from the image $g(x, y)$ by the transform

$$g'(x,y) = 255 - g(x,y). \tag{9.1}$$

Figure 9.5 shows an example of the contrast reversal transform that creates a negative image. (Photographic film captures a negative image that produces a positive image when a print is made.) This transform is commonly used to make x-ray and infrared images easier for untrained people to interpret by making the contrast of these images similar to the contrast of images captured in the visible spectrum. Note that the gray-level histogram of the output image is a mirror image of the gray-level histogram of the input image.

9.2.2 Contrast stretch

A high-contrast image spans the full range of gray-level values; therefore, a low-contrast image can be transformed into a high-contrast image by remapping or stretching the gray-level values such that the histogram spans the full range. The contrast stretch is often referred to as the dynamic range adjustment (DRA). The simplest contrast stretch is a linear transform that maps the lowest gray level GL_{min} in the image to zero and the highest value GL_{max} in the image to 255 (for an eight-bit image), with all other gray levels remapped linearly between zero and 255, to produce a high-contrast image that spans the full range of gray levels. This linear transform is given by

$$g'(x,y) = \mathrm{INT}\left\{\frac{255}{GL_{max} - GL_{min}}\left[g(x,y) - GL_{min}\right]\right\}, \tag{9.2}$$

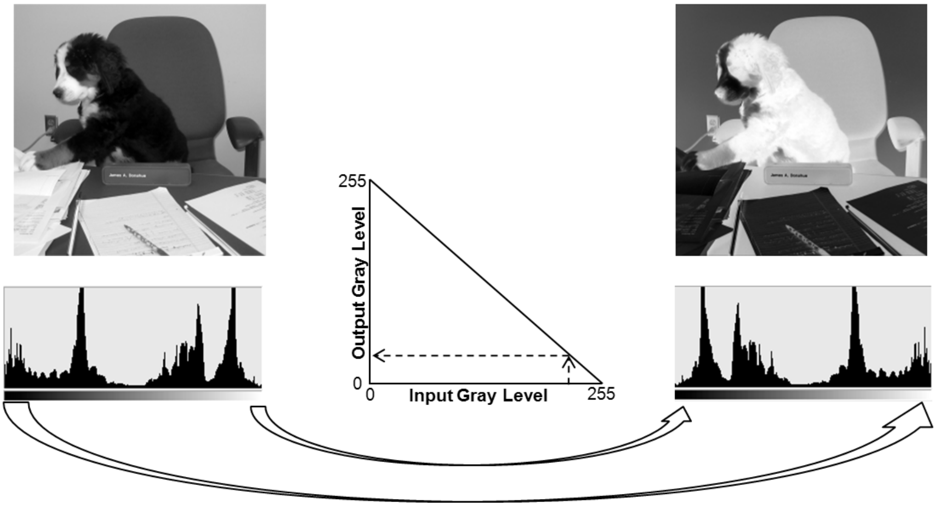

Figure 9.5 The contrast reversal transform.

where the INT function returns the integer value. If we wish to remap the image to a gray-level range defined by a new minimum GL'_{min} and a new maximum defined by GL'_{max}, the linear transform (Fig. 9.6) can be generalized to

$$g'(x,y) = \mathrm{INT}\left\{ \frac{GL'_{max} - GL'_{min}}{GL_{max} - GL_{min}} \left[g(x,y) - GL_{min} \right] + GL'_{min} \right\}. \quad (9.3)$$

The linear transform for contrast enhancement spreads the gray-level values evenly over the full contrast range available; thus, the relative shape of the histogram remains unchanged but is widened to fill the range. The stretching of the histogram creates evenly distributed gaps between gray-level values in the image. Note that although the linear transform will increase the contrast of the image, the steps between the populated gray-level values increase in contrast as well, which can result in visible contouring artifacts in the image (Fig. 9.7).

We can achieve additional contrast enhancement if we replace GL_{min} and GL_{max} in Eq. (9.3) with points that penetrate the gray-level histogram, with $P_{min} > GL_{min}$ penetrating the low end and $P_{max} < GL_{max}$ penetrating the high end. The gray-level transform is then given by

$$g'(x,y) = \mathrm{INT}\left\{ \frac{\left(GL'_{max} - GL'_{min}\right)}{P_{max} - P_{min}} \left[g(x,y) - P_{min} \right] + GL'_{min} \right\}. \quad (9.4)$$

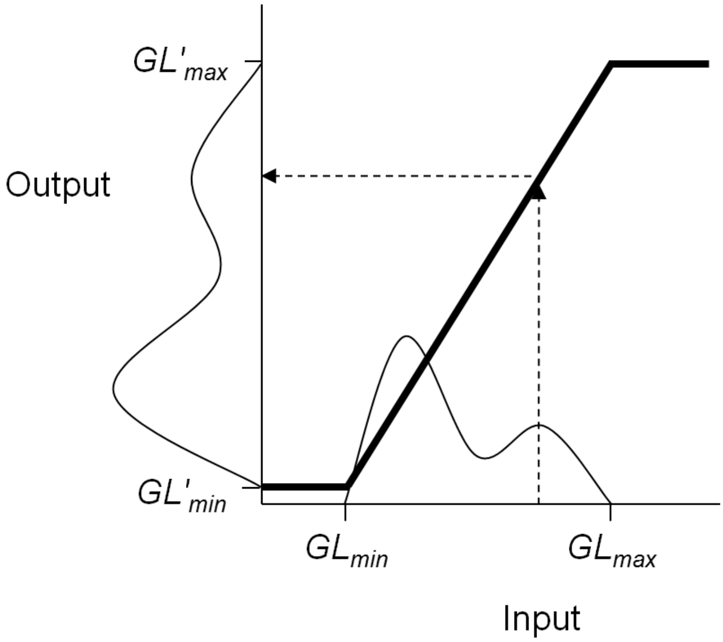

Figure 9.6 A Linear transform that remaps the gray levels between GL'_{min} and GL'_{max}.

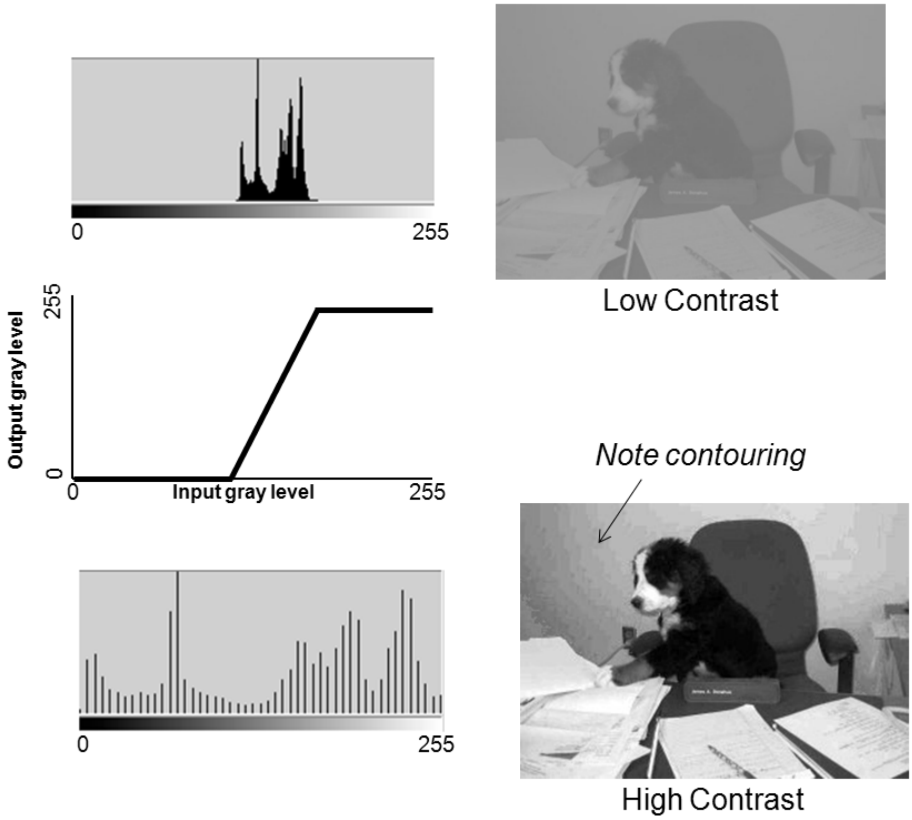

Figure 9.7 Enhancement of low-contrast images can produce image artifacts.

If $GL'_{min} = 0$ and $GL'_{max} = 255$, then the gray levels between GL_{min} and P_{min} will be clipped to zero and the gray levels between P_{max} and GL_{max} will be clipped to 255, but this may be a valid compromise to get the additional enhancement.

A useful calculation to help determine the best penetration points is the cumulative histogram, which is generated by finding the total number of pixels in the gray-level histogram between zero and each gray level. If the gray-level histogram is given by $P(GL)$, the cumulative histogram is given by

$$P_{cumm}\left(GL\right) = \sum_{i=0}^{GL} P\left(i\right). \tag{9.5}$$

The values for P_{min} and P_{max} can be calculated for each image using predefined percentages of the cumulative histogram that will be clipped to zero and 255 (Fig. 9.8). The gray-level histogram $P'(GL)$ of the processed image will cover the full contrast range but will also have more pixels at zero and 255 due to the clipping. Figure 9.9 illustrates an image processed with various penetration points.