is usually enough variability between images that, even if global thresholding is a suitable approach, an algorithm capable of estimating automatically the threshold value for each image is required. The following iterative algorithm can be used for this purpose:

1. Select an initial estimate for the global threshold, $T$.
2. Segment the image using $T$ in Eq. (10.3-1). This will produce two groups of pixels: $G_1$ consisting of all pixels with intensity values $> T$, and $G_2$ consisting of pixels with values $\leq T$.
3. Compute the average (mean) intensity values $m_1$ and $m_2$ for the pixels in $G_1$ and $G_2$, respectively.
4. Compute a new threshold value:

$$T = \frac{1}{2}(m_1 + m_2)$$

5. Repeat Steps 2 through 4 until the difference between values of $T$ in successive iterations is smaller than a predefined parameter $\Delta T$.

This simple algorithm works well in situations where there is a reasonably clear valley between the modes of the histogram related to objects and background. Parameter $\Delta T$ is used to control the number of iterations in situations where speed is an important issue. In general, the larger $\Delta T$ is, the fewer iterations the algorithm will perform. The initial threshold must be chosen greater than the minimum and less than maximum intensity level in the image (Problem 10.28). The average intensity of the image is a good initial choice for $T$.

**EXAMPLE 10.15:** Global thresholding.

■ Figure 10.38 shows an example of segmentation based on a threshold estimated using the preceding algorithm. Figure 10.38(a) is the original image, and Fig. 10.38(b) is the image histogram, showing a distinct valley. Application of the preceding iterative algorithm resulted in the threshold $T = 125.4$ after three iterations, starting with $T = m$ (the average image intensity), and using $\Delta T = 0$. Figure 10.38(c) shows the result obtained using $T = 125$ to segment the original image. As expected from the clear separation of modes in the histogram, the segmentation between object and background was quite effective. ■

The preceding algorithm was stated in terms of successively thresholding the input image and calculating the means at each step because it is more intuitive to introduce it in this manner. However, it is possible to develop a more efficient procedure by expressing all computations in the terms of the image histogram, which has to be computed only once (Problem 10.26).

### 10.3.3 Optimum Global Thresholding Using Otsu's Method

Thresholding may be viewed as a statistical-decision theory problem whose objective is to minimize the average error incurred in assigning pixels to two or more groups (also called *classes*). This problem is known to have an elegant closed-form solution known as the *Bayes decision rule* (see Section 12.2.2). The solution is based on only two parameters: the probability density function (PDF) of the intensity levels of each class and the probability that each class occurs in a given application. Unfortunately, estimating PDFs is not a trivial