CHAPTER 5

IMAGE SENSING AND ACQUISITION

WHAT WILL WE LEARN?

- What are the main parameters involved in the design of an image acquisition solution?
- How do contemporary image sensors work?
- What is image digitization and what are the main parameters that impact the digitization of an image or video clip?
- What is sampling?
- What is quantization?
- How can I use MATLAB to resample or requantize an image?

5.1 INTRODUCTION

In Chapter 1, we described an image as a two-dimensional (2D) representation of a real-world, three-dimensional (3D) object or scene and indicated that the existence of a light source illuminating the scene is a requirement for such an image to be produced. We also introduced the concept of a digital image as a representation of a two-dimensional image using a finite number of pixels.

In this chapter, we will expand upon those concepts. More specifically, we will look at relevant issues involved in acquiring and digitizing an image, such as the

Practical Image and Video Processing Using MATLAB®. By Oge Marques.

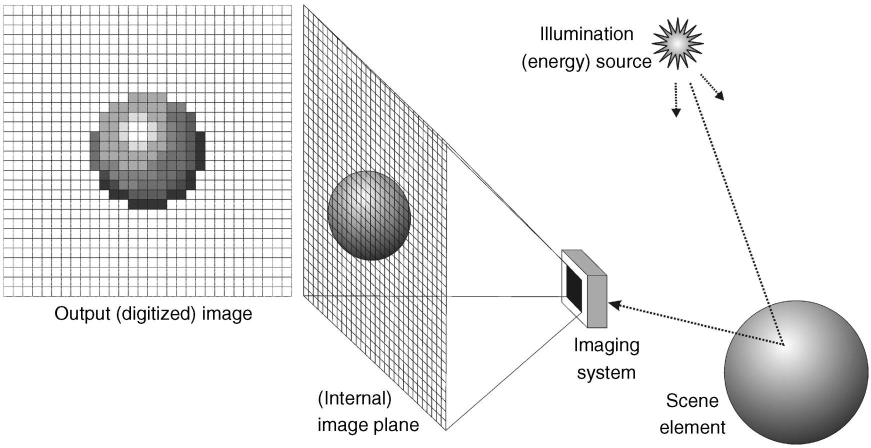


FIGURE 5.1 Image acquisition, formation, and digitization. Adapted and redrawn from [GW08].

principles of image formation as a result of reflection of light on an object or scene, the sensors typically used to capture the reflected energy, and the technical aspects involved in selecting the appropriate number of (horizontal and vertical) samples and quantization levels for the resulting image. In other words, we will present the information necessary to understand how we go from real-world scenes to 2D digital representations of those scenes. For the remaining chapters of Part I, we shall assume that such digital representations are available and will learn many ways of processing them, without looking back at how they were acquired.

Figure 5.1 shows a schematic view of the image acquisition, formation, and digitization process. The figure also highlights the need for an illumination (energy) source (see Section 5.2), the existence of an imaging sensor capable of converting optical information into its electrical equivalent (see Section 5.3), and the difference between the analog version of the image and its digitized equivalent, after having undergone sampling and quantization (see Section 5.4).

5.2 LIGHT, COLOR, AND ELECTROMAGNETIC SPECTRUM

The existence of light—or other forms of electromagnetic (EM) radiation—is an essential requirement for an image to be created, captured, and perceived. In this section, we will look at basic concepts related to light, the perception of color, and the electromagnetic spectrum.

5.2.1 Light and Electromagnetic Spectrum

Light can be described in terms of electromagnetic waves or particles, called *photons*. A photon is a tiny packet of vibrating electromagnetic energy that can be

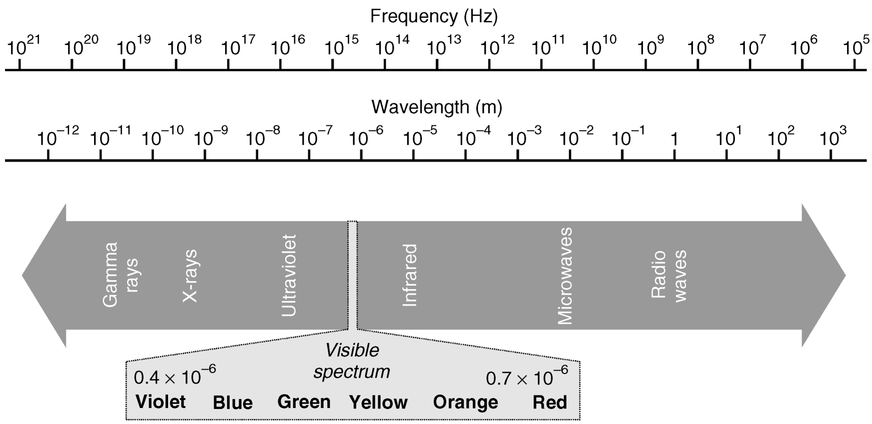


FIGURE 5.2 Electromagnetic spectrum.

characterized by its wavelength or frequency. Wavelength is usually measured in meters (and its multiples and submultiples). Frequency is measured in hertz (Hz) and its multiples. Wavelength (λ) and frequency (f) are related to each other by the following expression:

$$\lambda = \frac{v}{f} \tag{5.1}$$

where v is the velocity at which the wave travels, usually approximated to be equal to the speed of light (c): 2.998×10^8 m/s.

The human visual system (HVS) is sensitive to photons of wavelengths between 400 and 700 nm, where 1 nm $= 10^{-9}$ m. As shown in Figure 5.2, this is a fairly narrow slice within the EM spectrum, which ranges from *radio waves* (wavelengths of 1 m or longer) at one end to *gamma rays* (wavelengths of 0.01 nm or shorter) at the other end.

Even though much of the progress in image processing has been fostered by work on images outside the visible spectrum, captured with specialized sensors, this book will focus exclusively on images within the visible range of the EM spectrum. Light is the preferred energy source for most imaging tasks because it is safe, cheap, easy to control and process with optical hardware, easy to detect using relatively inexpensive sensors, and readily processed by signal processing hardware.

5.2.2 Types of Images

Images can be classified into three categories according to the type of interaction between the source of radiation, the properties of the objects involved, and the relative positioning of the image sensor (Figure 5.3) [Bov00c]:

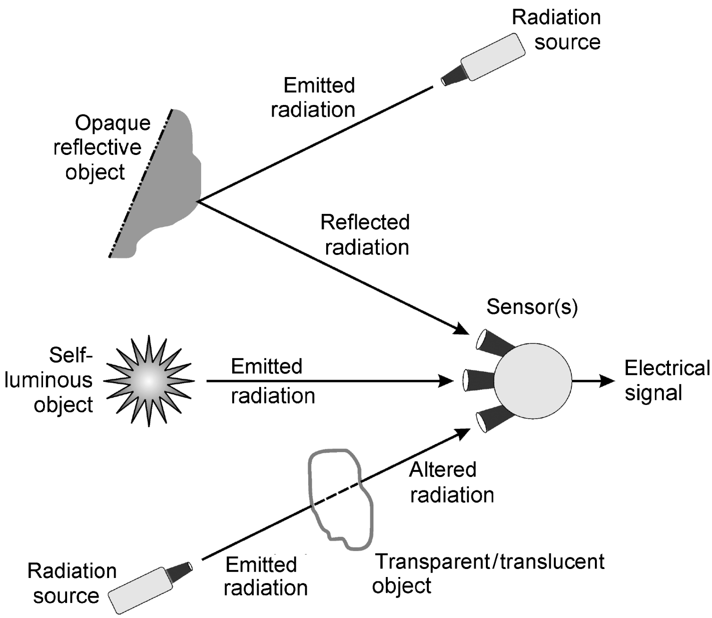


FIGURE 5.3 Recording the various types of interaction of radiation with objects and surfaces. Redrawn from [Bov00a].

- *Reflection Images*: These are the result of radiation that has been reflected from the surfaces of objects. The radiation may be *ambient* or *artificial*. Most of the images we perceive in our daily experiences are reflection images. The type of information that can be extracted from reflection images is primarily about surfaces of objects, for example, their shapes, colors, and textures.
- *Emission Images*: These are the result of objects that are self-luminous, such as stars and light bulbs (both within the visible light range), and—beyond visible light range—thermal and infrared images.
- *Absorption Images*: These are the result of radiation that passes through an object and results in an image that provides information about the object's internal structure. The most common example is X-ray image.

5.2.3 Light and Color Perception

Light is a particular type of EM radiation that can be sensed by the human eye. Colors perceived by humans are determined by the nature of the light reflected by the object, which is a function of the spectral properties of the light source as well as the absorption and reflectance properties of the object.

In 1666, Sir Isaac Newton discovered that a beam of sunlight passing through a prism undergoes decomposition into a continuous spectrum of components

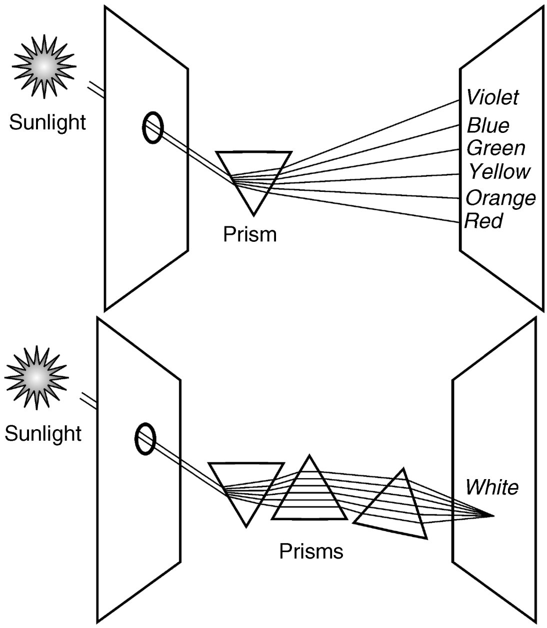


FIGURE 5.4 Newton's prism: many "colors" in the sunlight.

(Figure 5.4). Each of these components produces a different color experience, ranging from what we call *red* at one end to *violet* at the other. Newton's experiments and theories gave fundamental insights into the physical properties of light. They taught us that sunlight is actually composed of many different "colors" of light rather than just one. More important, the "colors" were not in the light itself but in the effect of the light on the visual system.

The radiance (physical power) of a light source is expressed in terms of its spectral power distribution (SPD). Figure 5.5 shows examples of SPDs of physical light sources commonly found in imaging systems: sunlight, tungsten lamp, light-emitting diode (LED), mercury arc lamp, and helium–neon laser. The human perception of each of these light sources will vary—from the yellowish nature of light produced by tungsten light bulbs to the extremely bright and pure red laser beam.

5.2.4 Color Encoding and Representation

Color can be encoded using three numerical components and appropriate spectral weighting functions. *Colorimetry* is the science that deals with the quantitative study of color perception. It is concerned with the representation of *tristimulus values*, from which the perception of color is derived. The simplest way to encode color in cameras and displays is by using the red (R), green (G), and blue (B) values of each pixel.

Human perception of light—and, consequently, color—is commonly described in terms of three parameters:

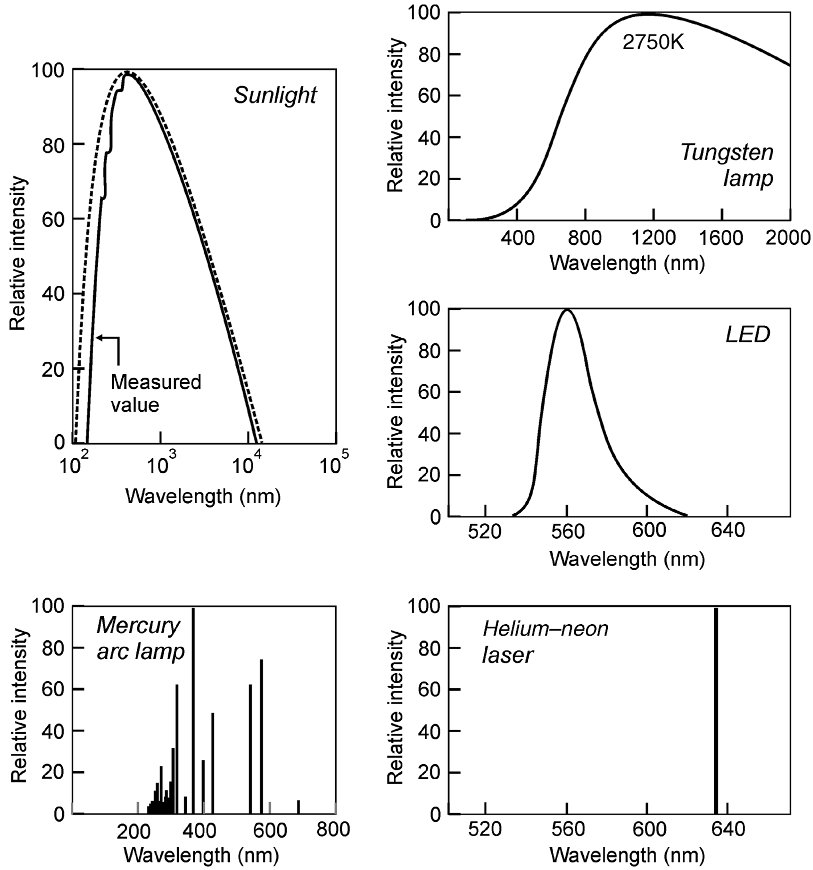


FIGURE 5.5 Spectral power distributions of common physical light sources. Redrawn from [Pra07].

- *Brightness*: The *subjective* perception of (achromatic) luminous intensity, or "the attribute of a visual sensation according to which an area appears to emit more or less light" [Poy03].
- *Hue*: "The attribute of a visual sensation according to which an area appears to be similar to one of the perceived colors, red, yellow, green and blue, or a combination of two of them" [Poy03]. From a spectral viewpoint, hue can be associated with the dominant wavelength of an SPD.
- *Saturation*: "The colorfulness of an area judged in proportion to its brightness" [Poy03], which usually translates into a description of the whiteness of the light source. From a spectral viewpoint, the more an SPD is concentrated at one wavelength, the more saturated will be the associated color. The addition of white light, that is, light that contains power at all wavelengths, causes color desaturation.

It is important to note that saturation and brightness are perceptual quantities that cannot be measured. The *Commission Internationale de L'Éclairage* (International Commission on Illumination, or simply CIE)—the international body responsible for standards in the field of color—has defined an objective quantity that is related to brightness: it is called *luminance*. Luminance can be computed as a weighted sum of red, green and blue components present in the image. We shall resume the discussion of color perception and representation in Chapter 16.

5.3 IMAGE ACQUISITION

In this section, we describe the basics of image acquisition and its two main building blocks: the image sensor and the optics associated with it.

5.3.1 Image Sensors

The main goal of an image sensor is to convert EM energy into electrical signals that can be processed, displayed, and interpreted as images. The way this is done varies significantly from one technology to another. The technology for image sensors has changed dramatically over the past 50 years, and sensors have shifted from vacuum tubes to solid-state devices, notably based on CCDs (charge-coupled devices) and CMOS (complementary metal oxide semiconductor) technologies.

Two of the most popular and relatively inexpensive devices used for image acquisition are the digital camera and the flatbed scanner. Cameras typically use 2D (area) CCD sensors, whereas scanners employ 1D (line) CCDs that move across the image as each row is scanned. CCDs have become the sensor of choice in many imaging applications because they do not suffer from geometric distortions and have a linear response to incident light [Eff00].

A CCD sensor is made up of an array of light-sensitive cells called *photosites*, manufactured in silicon, each of which produces a voltage proportional to the intensity of light falling on them. A photosite has a finite capacity of about 10^6 energy carriers, which imposes an upper bound on the brightness of the objects to be imaged. A saturated photosite can overflow, corrupting its neighbors and causing a defect known as *blooming*.

The *nominal resolution* of a CCD sensor is the size of the scene element that images to a single pixel on the image plane. For example, if a 20 cm $\times$ 20 cm square sheet of paper is imaged to form a 500 $\times$ 500 digital image, then the nominal resolution of the sensor is 0.04 cm.

The *field of view* (FOV) of an imaging sensor is a measure of how much of a scene it can see, for example, 10 cm $\times$ 10 cm. Since this may vary with depth, it is often more meaningful to refer to the *angular field of view*, for example, $55^\circ \times 40^\circ$.

A CCD camera sometimes plugs into a computer board, called *frame buffer*, which contains fast access memory (typically 0.1 ms per image) for the images captured by the camera. After being captured and temporarily stored in the frame buffer, images can be processed or copied to a long-term storage device, for example, a hard drive.

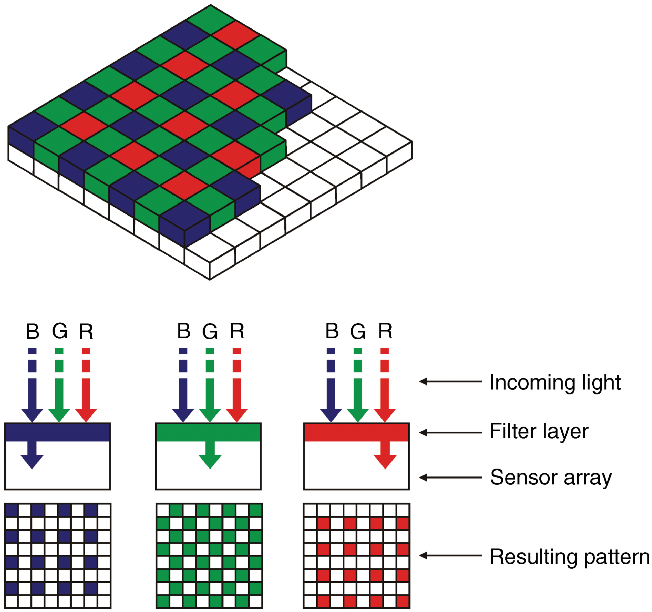


FIGURE 5.6 The Bayer pattern for single-CCD cameras.

Many contemporary cameras interface with the computer via fast standardized digital interfaces such as Firewire (IEEE 1394), Camera Link, or fast Ethernet. Such interfaces are already digital and therefore do not require a frame grabber. Moreover, most digital cameras and camcorders also include a generous amount of local storage media (e.g., from recordable CD or DVD to a myriad of specialized cards and memory sticks) that allow a significant amount of information to be locally stored in the device before being transferred to a computer.

In single-CCD cameras, colors are obtained by using a *tricolor imager* with different photosensors for each primary color of light (red, green, and blue), usually arranged in a Bayer pattern (Figure 5.6). In those cases, each pixel actually records only one of the three primary colors; to obtain a full-color image, a *demosaicing algorithm*—which can run inside the actual camera, before recording the image in JPEG format, or in a separate computer, working on the raw output from the camera—is used to interpolate a set of complete R, G, and B values for each pixel.

More expensive cameras use three CCDs, one for each color, and an *optical beam splitter* (Figure 5.7). Beam splitters have been around since the days of Plumbicon tubes. They are made of prisms with *dichroic* surfaces, that is, capable of reflecting light in one region of the spectrum and transmitting light that falls elsewhere.

An alternative technology to CCDs is CMOS. CMOS chips have the advantages of being cheaper to produce and requiring less power to operate than comparable CCD chips. Their main disadvantage is the increased susceptibility to noise, which limits their performance at low illumination levels. CMOS sensors were initially

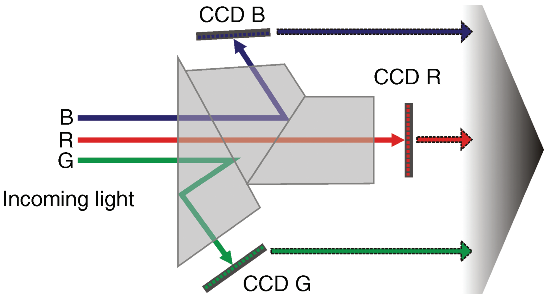


FIGURE 5.7 The beam splitter for three-CCD color cameras.

used in low-end cameras, such as webcams, but have recently been extended to much more sophisticated cameras, including the Panavision HDMAX 35 mm video camera.

A representative recent example of CMOS sensors is the Foveon X3 sensor (Figure 5.8), a CMOS image sensor for digital cameras, designed by Foveon, Inc. and manufactured by National Semiconductor. It has been designed as a layered sensor stack, in which each location in a grid has layered photosensors sensitive to all three primary colors, in contrast to the mosaic Bayer filter sensor design commonly used in digital camera sensors where each location is a single photosensor (pixel) sensitive to only one primary color. To perform its function, the Foveon sensor utilizes

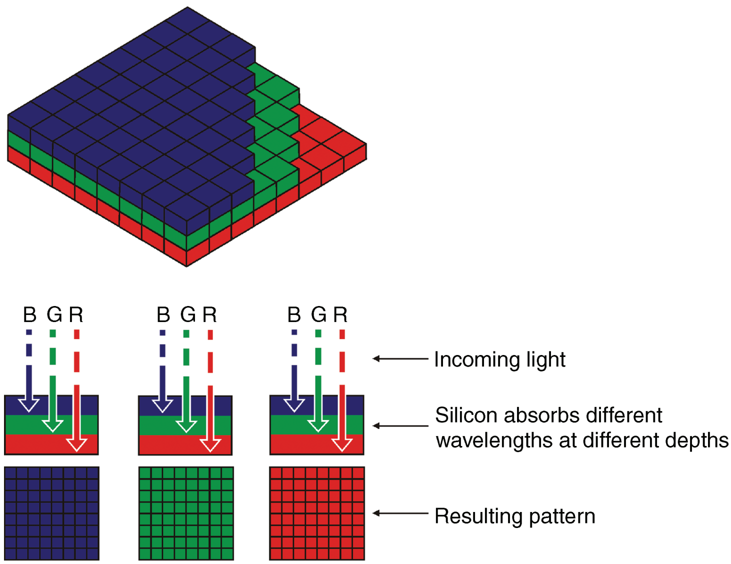


FIGURE 5.8 X3 color sensor.

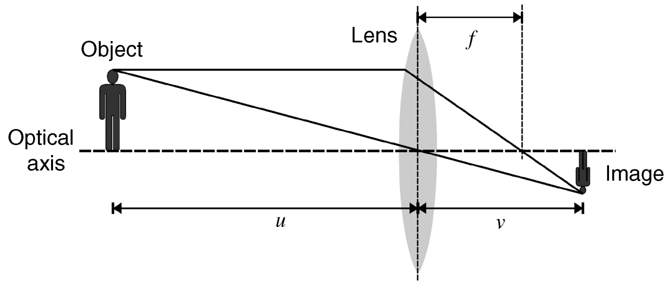


FIGURE 5.9 Image formation using a lens.

the physical property that different wavelengths of light penetrate silicon to different depths.

5.3.2 Camera Optics

A camera uses a lens to focus part of the scene onto the image sensor. Two of the most important parameters of a lens are its magnifying power and light gathering capacity. Magnifying power can be specified by a *magnification factor* (m), which is the ratio between image size and object size:

$$m = \frac{v}{u} \tag{5.2}$$

where u is the distance from an object to the lens and v is the distance from the lens to the image plane (Figure 5.9).

The magnifying power of a lens is usually expressed in terms of its *focal length*, f (in millimeters), the distance from the lens to the point at which parallel incident rays converge (Figure 5.9), given by the lens equation:

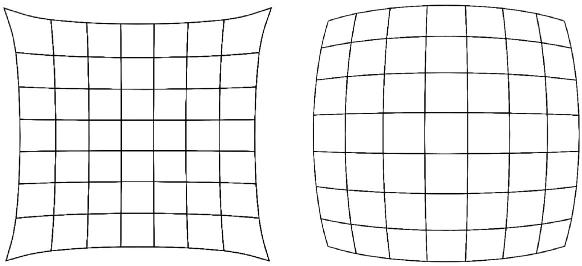
$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \tag{5.3}$$

Combining equations (5.2) and (5.3), we can express f as a function of u and m:

$$f = \frac{um}{m+1} \tag{5.4}$$

Equation (5.4) provides a practical and convenient way to determine the focal length for a certain magnification factor and object distance and select the appropriate lens for the job.

The light gathering capacity of a camera lens is determined by its *aperture*, which is often expressed as an "f number"—a dimensionless value that represents the ratio between focal length and aperture diameter. Most lenses have a sequence of fixed apertures (e.g., $f2.8$, $f4$, $f5.6$, $f8$, $f11$) that progressively reduce the total amount of light reaching the sensor by half.



(a) (b)

FIGURE 5.10 Examples of lens aberrations: (a) pincushion distortion; (b) barrel distortion.

Lenses may suffer from *aberrations*, which can affect image quality and generate undesired distortions on the resulting image. Examples of such aberrations include—among many others—the *pincushion distortion* and the *barrel distortion* (Figure 5.10). If such defects are not taken care of by the lens system itself, certain image processing techniques[1] can be used to correct them.

In MATLAB

The MATLAB Image Acquisition Toolbox (IAT) is a collection of functions that extend the capability of MATLAB, allowing image acquisition operations from a variety of image acquisition devices, from professional-grade frame grabbers to USB-based webcams. The IAT software uses components called *hardware device adaptors* to connect to devices through their drivers (Figure 5.11). At the time of this writing, the IAT supports a variety of devices and drivers, such as the IIDC 1394-based Digital Camera Specification (DCAM), and devices that provide Windows Driver Model (WDM) or Video for Windows (VFW) drivers, such as USB and IEEE 1394 (FireWire, i.LINK) Web cameras, digital video (DV) camcorders, and TV tuner cards. Since the release of Version 3.0, the functionality of the IAT software is available in a desktop application.

5.4 IMAGE DIGITIZATION

The image digitization stage bridges the gap between the analog natural world, from which scenes are acquired, and the digital format expected by computer algorithms in charge of processing, storing, or transmitting this image.

Digitization involves two processes (Figure 5.12): *sampling* (in time or space) and *quantization* (in amplitude). These operations may occur in any sequence, but usually sampling precedes quantization [Poy03]. Sampling involves selecting a finite number of points within an interval, whereas quantization implies assigning an amplitude

[1] Some of these techniques will be discussed in Chapter 7.

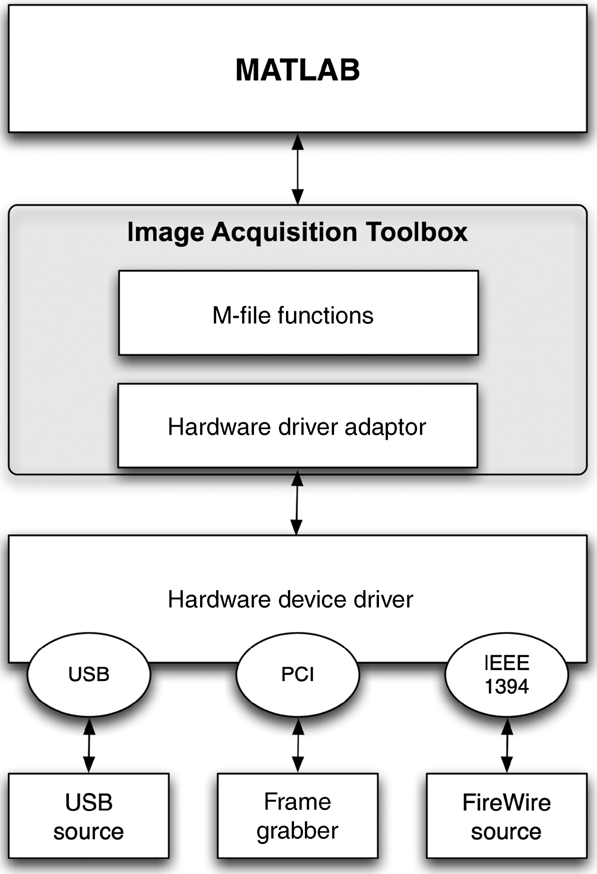


FIGURE 5.11 The main components of the MATLAB Image Acquisition Toolbox.

value (within a finite range of possible values) to each of those points. The result of the digitization process is a *pixel array*, which is a rectangular matrix of picture elements whose values correspond to their intensities (for monochrome images) or color components (for color images).

For consumer cameras and camcorders, it has become common to refer to the size of the pixel array by the product of the number of pixels along each dimension and express the result in megapixels (Mpx).[2] Figure 5.13 shows representative contemporary pixel arrays ranging from the QCIF videoconferencing standard (to be discussed in Chapter 20) to the 1920 $\times$ 1080 HDTV standard.

[2]It has also become common practice to associate image quality with the size of the camera's resulting pixel array, which is certainly one of the parameters to keep in mind when shopping for a new camera, but by no means the only one. Many other features—from the amount of optical zoom to the ability of working under low lighting—may turn out to be more relevant to the user.

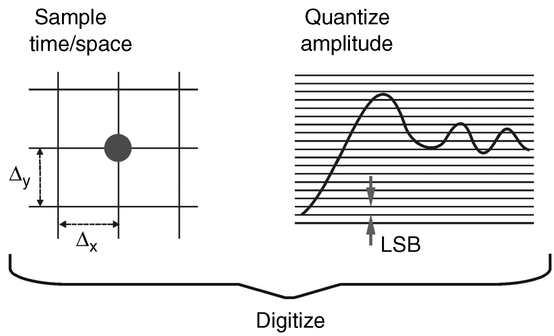


FIGURE 5.12 Digitization = sampling + quantization. Redrawn from [Poy03].

Digitization can take place in many different portions of a machine vision system (MVS) and has been moving progressively closer to the camera hardware during the past few years, making products such as "video capture cards" or "frame grabbers" more of a rarity.

5.4.1 Sampling

Sampling is the process of measuring the value of a 2D function at discrete intervals along the x and y dimensions. A system that has equal horizontal and vertical sampling densities is said to have *square sampling*. Several imaging and video systems use sampling lattices where the horizontal and the vertical sample pitch are unequal, that is, *nonsquare sampling*.

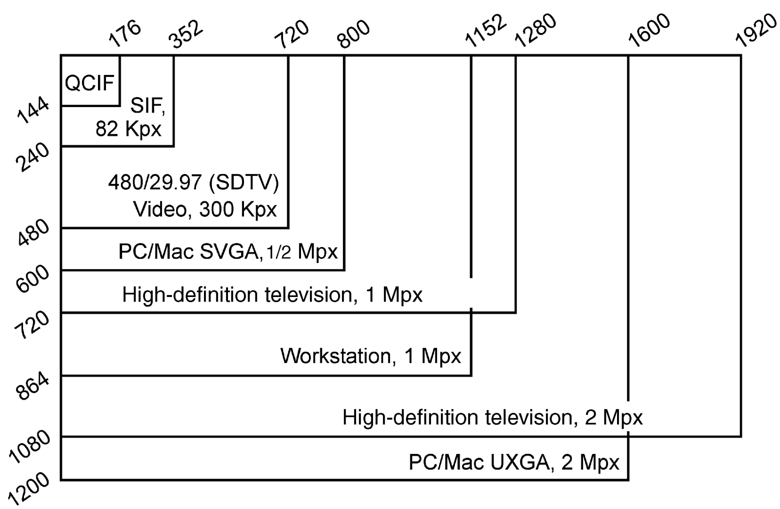


FIGURE 5.13 Pixel arrays of several imaging standards. Redrawn from [Poy03].

Two parameters must be taken into account when sampling images:

1. The *sampling rate*, that is, the number of samples across the height and width of the image. The choice of an appropriate sampling rate will impact image quality, as we shall see in Section 5.4.3. Inadequate values may lead to a phenomenon known as *aliasing*, which will be discussed later.
2. The *sampling pattern*, that is, the physical arrangement of the samples. A rectangular pattern, in which pixels are aligned horizontally and vertically into rows and columns, is by far the most common form, but other arrangements are possible, for example, the *hexagonal* and *log-polar* sampling patterns (see [SSVPB02] for an example).

If sampling takes place at a rate lower than twice the highest frequency component of the signal (the *Nyquist criterion*), there will not be enough points to ensure proper reconstruction of the original signal, which is referred to as *undersampling* or *aliasing*. Figure 5.14 illustrates the concept for 1D signals: part (a) shows the sampling process as a product of a train of sampling impulses and the analog signal being sampled, part (b) shows the result of reconstructing a signal from an appropriate number of samples, and part (c) shows that the same number of samples as in (b) would be insufficient to reconstruct a signal with higher frequency. The effect of aliasing on images is typically perceived in the form of Moiré patterns (which can be seen in the changes in the tablecloth pattern in Figure 5.16c and especially d).

In the case of temporal sampling (to be discussed again in Chapters 20 and 21), a very familiar example of the aliasing phenomenon is the *wagon wheel effect*, in which the spoked wheels of a wagon appear to be moving backward if the wagon moves at a speed that violates Nyquist theorem for the minimum number of temporal samples per second that would be required to display the proper motion.

5.4.2 Quantization

Quantization is the process of replacing a continuously varying function with a discrete set of quantization levels. In the case of images, the function is $f(x, y)$ and the

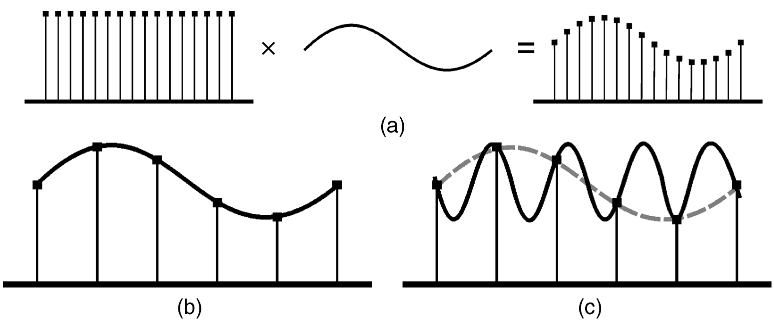


FIGURE 5.14 1D aliasing explanation. Redrawn from [Wat00].

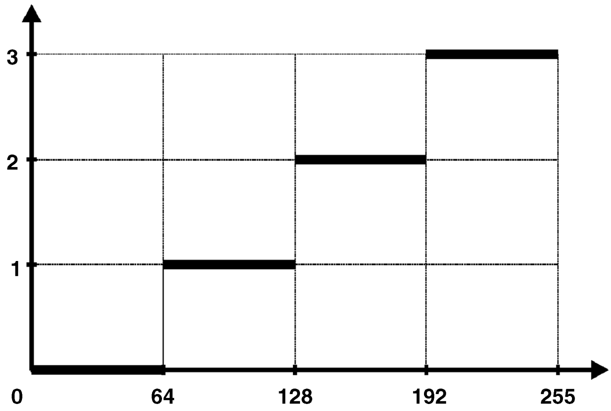


FIGURE 5.15 A mapping function for uniform quantization ($N = 4$).

quantization levels are also known as *gray levels*. It is common to adopt N quantization levels for image digitization, where N is usually an integral power of 2 that is, $N = 2^n$, where n is the number of bits needed to encode each pixel value. The case where $n = 2^8 = 256$ produces images where each pixel is represented by an unsigned byte, with values ranging from 0 (black) to 255 (white).

Image quantization can be described as a mapping process by which groups of data points (several pixels within a range of gray values) are mapped to a single point (i.e., a single gray level). This process is illustrated in Figure 5.15, which depicts the case where the number of gray levels is reduced from 256 to 4 by *uniform quantization*, meaning that the input gray level range is divided into N equal intervals of length 64.

5.4.3 Spatial and Gray-Level Resolution

Spatial resolution is a way of expressing the density of pixels in an image: the greater the spatial resolution, the more pixels are used to display the image within a certain fixed physical size. It is usually expressed quantitatively using units such as dots per inch (dpi).

■ EXAMPLE 5.1

Figure 5.16 shows the effects of reducing the spatial resolution of a 256-gray-level image. The original image (Figure 5.16a) is of size 1944 × 2592 and it is displayed at 1250 dpi. The three other images (Figure 5.16b through d) have reduced spatial resolution to 300, 150, and 72 dpi, respectively. They have been zoomed back to their original sizes in order to make meaningful comparisons. A close inspection of the results will show that the quality loss between the original image and its 300 dpi equivalent (Figure 5.16a and b) is not very noticeable, but the pixelation, jaggedness, loss of detail, and even the appearance of Moiré patterns present on the other two images (bottom row) are easy to notice.

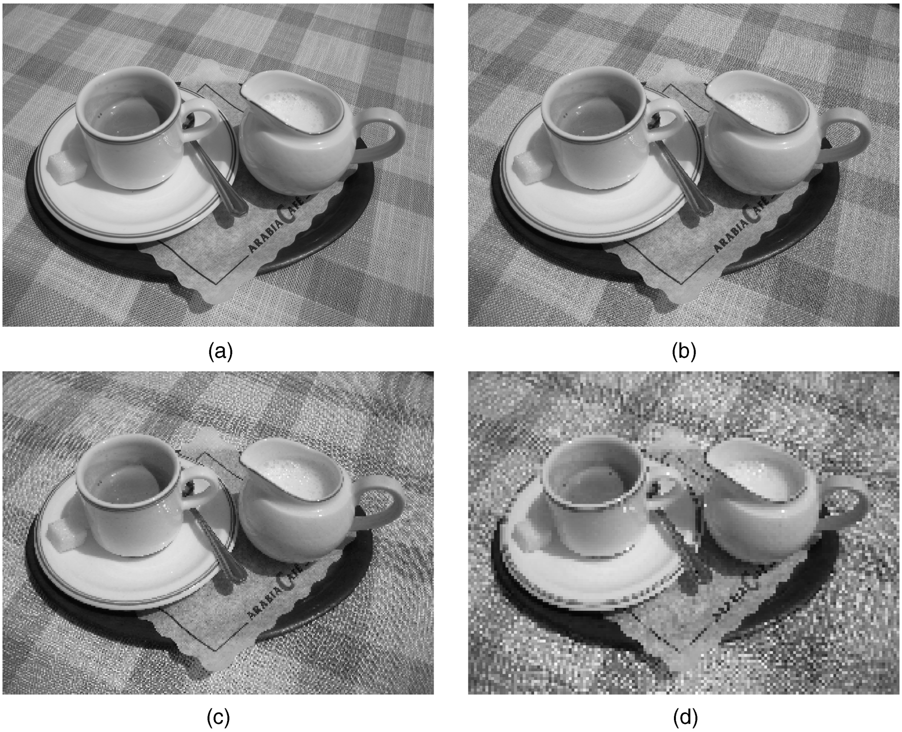


FIGURE 5.16 Effects of sampling resolution on image quality: (a) A 1944 $\times$ 2592 image, 256 gray levels, at a 1250 dpi resolution. The same image resampled at (b) 300 dpi; (c) 150 dpi; (d) 72 dpi.

Gray-level resolution refers to the smallest change in intensity level that the HVS can discern. The adoption of 8 bits per pixel for monochrome images is a good compromise between subjective quality and practical implementation (each pixel value is neatly aligned with a byte). Higher end imaging applications may require more than 8 bits per color channel and some image file formats support such need (e.g., 12-bit RAW and 16-bit TIFF files).

In MATLAB

(Re-)quantizing an image in MATLAB can be accomplished using the `grayslice` function, as illustrated in the following example.

■ EXAMPLE 5.2

Figure 5.17 shows the effects of quantization (gray) levels on image quality for an image with 480 $\times$ 640 pixels, starting with 256 gray levels and reducing it by a factor of 2 several times, until arriving at a binary version of the original image. A close inspection of the results will show that the quality loss between the original image and its 32 gray levels equivalent is not very noticeable (Figure 5.17a–d), but the quality

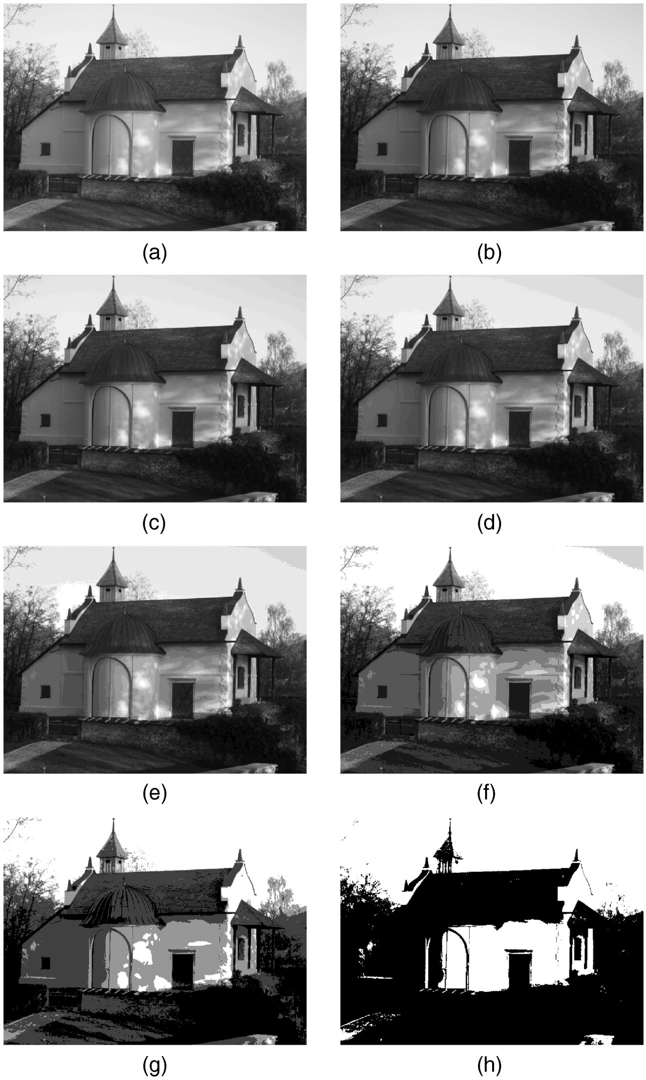


FIGURE 5.17 (a) A 480 × 640 image, 256 gray levels; (b–h) image requantized to 128, 64, 32, 16, 8, 4, and 2 gray levels.

of the last four images is unacceptable for most purposes due to the presence of *false contouring* and loss of relevant detail.

MATLAB Code

```
I1 = imread('ml_gray_640_by_480_256.png');
I2 = grayslice(I1,128); figure, imshow(I2,gray(128));
I3 = grayslice(I1,64); figure, imshow(I3,gray(64));
```

```
I4 = grayslice(I1,32); figure, imshow(I4,gray(32));
I5 = grayslice(I1,16); figure, imshow(I5,gray(16));
I6 = grayslice(I1,8); figure, imshow(I6,gray(8));
I7 = grayslice(I1,4); figure, imshow(I7,gray(4));
I8 = grayslice(I1,2); figure, imshow(I8,gray(2));
```

The choice of sampling and quantization parameters (total number of pixels and the number of gray levels per pixel) has also an impact on the resulting image file size. For example, a 1024×1024 image with 256 gray levels (8 bits per pixel) would require 1024^2 bytes, that is, 1 MB of disk space (neglecting any extra bytes needed for additional information, typically stored in the file header). Not too long ago, these image sizes were considered prohibitively large, which fostered the progress of image compression techniques and the standardization of file formats such as GIF and JPEG (see Chapter 17 for more details). In recent years, with significant increase in storage capacity at decreasing costs, the concern for disk space usage has been alleviated to some degree. Many digital image users would rather adopt more expansive file sizes than sacrifice the quality of their digital images. This has been seen in digital photography, with the creation and popularization of RAW file formats and increasing interest in images with more than 8 bits per pixel per color channel.

In summary, the choice of the number of samples per unit of distance (or area) (spatial resolution) and the number of colors or quantization (gray) levels used when digitizing an image should be guided by a trade-off between the impact on the storage size and the perceived resulting quality.

WHAT HAVE WE LEARNED?

- Images are formed as a result of the interaction between the source of radiation (e.g., visible light), the properties of the objects and surfaces involved, and the relative positioning and properties of the image sensor.
- Images can be classified into three categories according to the type of interaction between the source of radiation, the properties of the objects involved, and the relative positioning of the image sensor: reflection images, emission images, and absorption images.
- Contemporary image sensors (*imagers*) are usually built upon CCD or CMOS solid-state technologies. A CCD sensor is made up of an array of light-sensitive cells called “photosites,” each of which produces a voltage proportional to the intensity of light falling on them. The cells are combined into a (1D or 2D) array that can be read sequentially by a computer input process.
- Image digitization is the process of sampling a continuous image (in space) and quantizing the resulting amplitude values so that they fall within a finite range.
- Some of the main parameters that impact the digitization of an image are the total number of pixels and the maximum number of colors (or gray levels) per pixel.

- Sampling is the process of measuring the value of a function at discrete intervals. (Re-)sampling an image in MATLAB can be accomplished using the `imresize` function.
- Quantization is the process of replacing a continuously varying function with a discrete set of quantization levels. (Re-)quantizing an image in MATLAB can be accomplished using the `grayslice` function.

LEARN MORE ABOUT IT

- For a much more detailed treatment of photometry and colorimetry, we recommend Chapter 3 of [Pra07] and the Appendix B of [Poy03].
- For a brief discussion and visual examples of images acquired in different ranges of the EM spectrum, we recommend Section 2.2.2 of [Umb05] and Section 1.3 of [GW08].
- Chapter 9 of [LI99], Section 6 of [WB00], and Chapter 3 of [GH99] provide a good overview of video cameras' components, principles, and technologies.
- The development of the X3 sensor by Foveon and the implications of that technological breakthrough have become the subject of a book by Gilder [Gil05].

ON THE WEB

- Charles Poynton's *Frequently Asked Questions about Color*
  http://poynton.com/ColorFAQ.html
- The MATLAB Image Acquisition Toolbox
  http://www.mathworks.com/products/imaq/
- Edmund Optics
  http://www.edmundoptics.com/
- The Imaging Source
  http://www.theimagingsource.com/en/products/

5.5 PROBLEMS

5.1 Experiment with a scanner's settings (in dpi) and scan the same material (e.g., a photo) several times using different settings but the same file format. Compare the resulting file size and quality for each resulting scanned image.

5.2 Repeat Problem 5.1, but this time keeping the settings the same and changing only the file format used to save the resulting image. Are there significant differences in file size? What about the subjective quality?

5.3 Assuming a monochrome image with 1024×1024 pixels and 256 gray levels,

(a) Calculate the total file size (in bytes), assuming a header (containing basic information, such as width and height of the image) of 32 bytes and no compression.

(b) Suppose the original image has been subsampled by a factor of 2 in both dimensions. Calculate the new file size (in bytes), assuming the header size has not changed.

(c) Suppose the original image has been requantized to allow encoding 2 pixels per byte. Calculate the new file size (in bytes), assuming the header size has not changed.

(d) How many gray levels will the image in part (c) have?