Chapter 1 Introduction

One picture is worth more than ten thousand words.

1.1 What Is Digital Image Processing?

An image may be defined as a two-dimensional function, $f(x,y)$, where x and y are spatial (plane) coordinates. The amplitude of f at any pair of coordinates (x,y) is called the intensity or gray level of the image at that point.

When x, y, and f are all finite, discrete quantities, we call the image a digital image.

The field of digital image processing refers to processing digital images by means of a digital computer.

A digital image is composed of a finite number of elements, each of which has a location and value. These elements are called pixels.

Unlike humans, who are limited to the visual band of electromagnetic (EM) spectrum, imaging machines cover almost the entire EM spectrum, ranging from gamma to radio waves.

There is no general agreement among authors regarding where image processing stops and other related areas, such as image analysis and computer vision, starts.

Although there are no clear-cut boundaries in the continuum from image processing at one end to computer vision at the other, one useful paradigm is to consider three types of processes in this continuum:

> A low-level process is characterized by the fact that both its inputs and outputs are images.

A mid-level process is characterized by the fact that its inputs generally are images, but its outputs are attributes extracted from those images.

The higher-level processes include object recognition, image analysis, and performing the cognitive functions associated with vision.

1.2 The Origins of Digital Image Processing?

One of the first applications of digital images was in the newspaper industry, when pictures were first sent by submarine cable between London and New York.

Introduction of the Bartlane cable picture transmission system in the early 1920s reduced the time to transport a picture across the Atlantic from more than one week to less than three hours.

FIGURE 1.1 A digital picture produced in 1921 from a coded tape by a telegraph printer with special type faces. (McFarlane.[†])

Some of the initial problems in improving the visual quality of these early digital pictures were related to the selection of printing procedures and the distribution of intensity levels.

The printing method used to obtain Figure 1.1 was abandoned toward the end of 1921 in favour of a technique based on photographic reproduction made from tapes perforated at the telegraph receiving terminal.

FIGURE 1.2 A digital picture made in 1922 from a tape punched after the signals had crossed the Atlantic twice. (McFarlane.)

The early Bartlane systems were capable of coding images in five levels of gray. This capability was increased to 15 levels in 1929.

FIGURE 1.3 Unretouched cable picture of Generals Pershing and Foch, transmitted in 1929 from London to New York by 15-tone equipment. (McFarlane.)

The history of digital image processing is tied to the development of the digital computer.

The first computers powerful enough to carry out meaningful image processing tasks appeared in the early 1960s.

FIGURE 1.4 The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9 : 09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

In parallel with space applications, digital image processing techniques were used in medical imaging, remote Earth resources observations, and astronomy in the late 1960s and early 1970s.

The invention in the early 1970s of computerized axial tomography (CAT), also called computerized tomography (CT), is one of the most important events in the application of image processing in medical diagnosis.

The field of image processing has grown vigorously since 1960s, and the image processing techniques now are used in a broad range of applications.

Other than the processing intended for human interpretation, another important area of applications of digital image processing is in solving problems dealing with machine perception.

Typical problems in machine perception that routinely utilize image processing techniques are automatic character recognition, industrial machine vision, military recognizance, processing of fingerprints, and many other tasks.

The continuing decline in the ratio of computer price to performance and the expansion of networking and communication bandwidth via World Wide Web and the Internet have created unprecedented opportunities for continued growth of digital image processing.

1.3 Examples of Field that Use Digital Image Processing

One of the simplest ways to develop a basic understanding of the extent of image processing applications is to categorize images according to their source.

The principal energy source for images in use today is the electromagnetic (EM) energy spectrum.

Electromagnetic waves can be conceptualized as propagating sinusoidal waves of varying wavelengths, or they can be though of as a stream of massless particles traveling in a wavelike pattern and moving at the speed of light. Each massless particle contains a certain amount (or bundle) of energy.

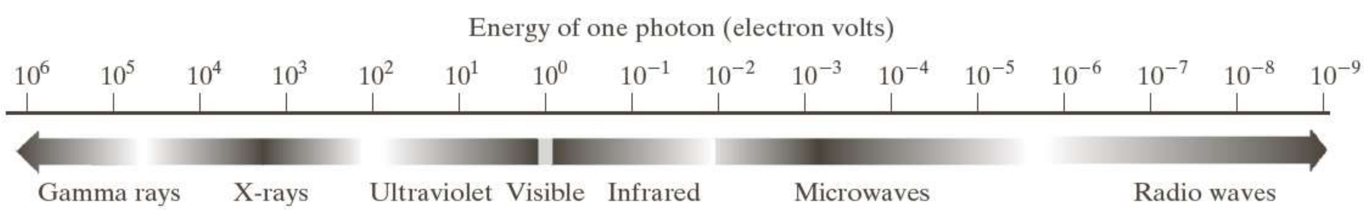


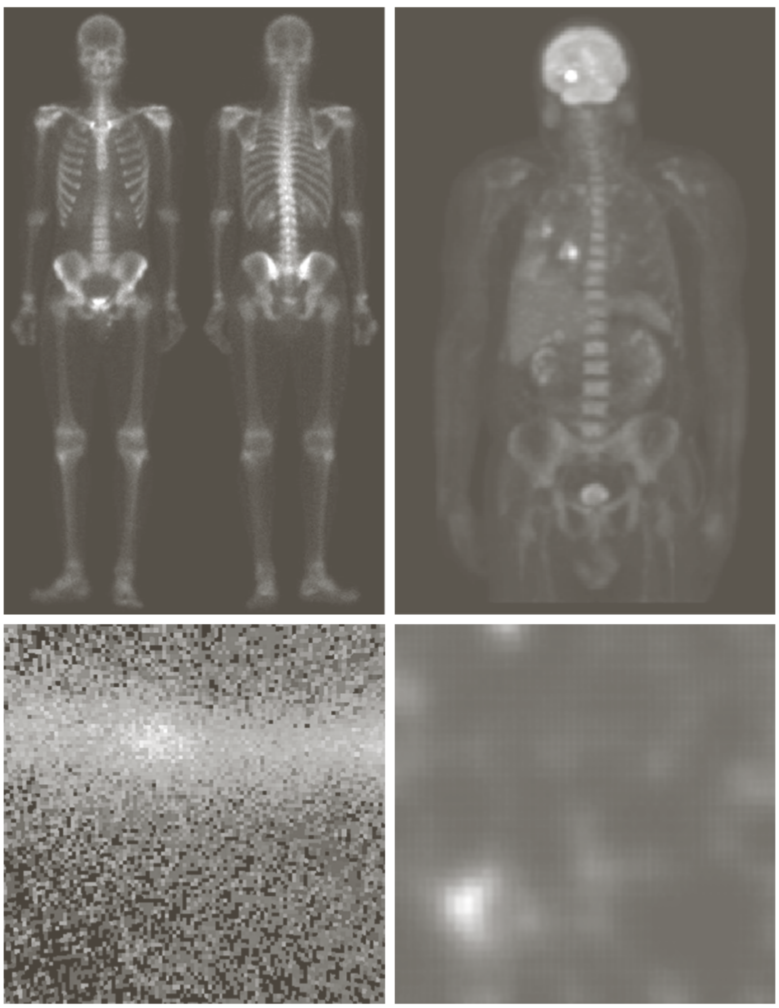
FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

Gamma-Ray Imaging

Major uses of imaging based on gamma rays include nuclear medicine and astronomical observations.

Images are produced from emissions collected by gamma ray detectors.

Figure 1.6 shows some examples of gamma-ray imaging.



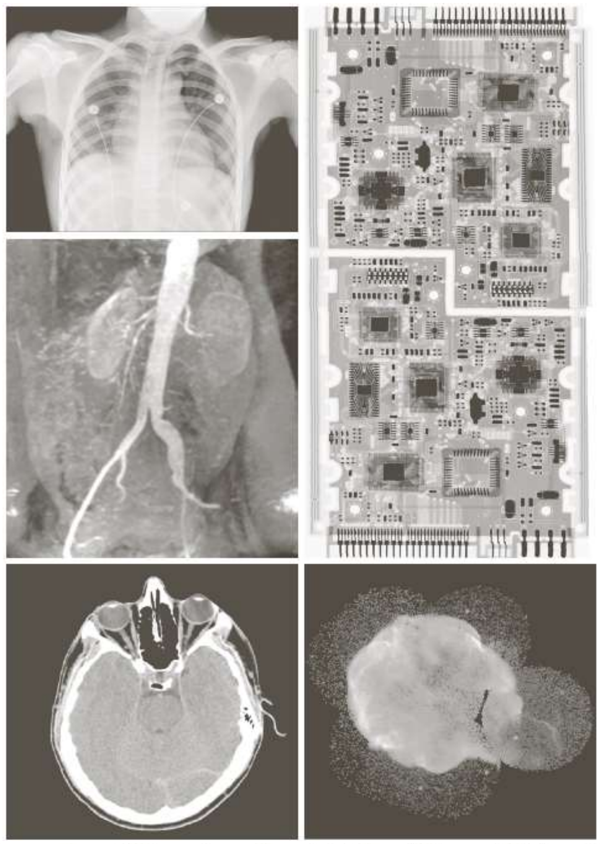
a b
c d

FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems, (b) Dr. Michael E. Casey, CTI PET Systems, (c) NASA, (d) Professors Zhong He and David K. Wehe, University of Michigan.)

X-Ray Imaging

X-rays are among the oldest sources of EM radiation used for imaging.

Figure 1.7 shows some examples of X-ray imaging.



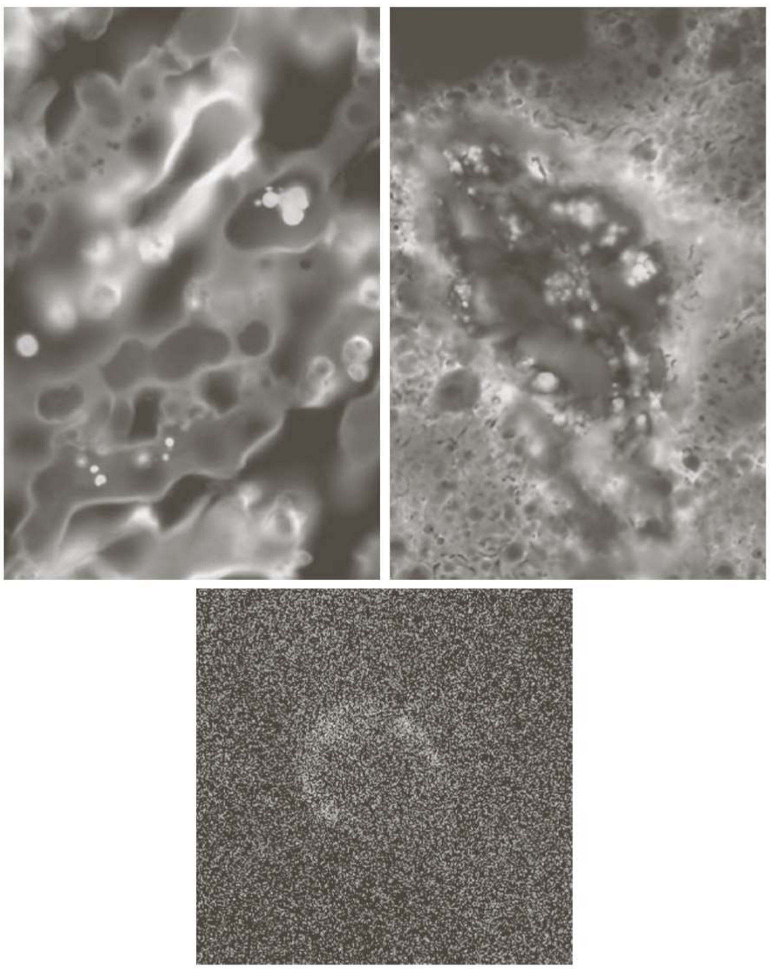
a d
b
c e

FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center; (b) Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School; (d) Mr. Joseph E. Pascente, Lixi, Inc.; and (e) NASA.)

Imaging in the Ultraviolet Band

Applications of ultraviolet "light" are varied. They include lithography, industrial inspection, microscopy, lasers, biological imaging, and astronomical observations.

Figure 1.8 shows some examples of ultraviolet imaging.



a b
c

FIGURE 1.8 Examples of ultraviolet imaging. (a) Normal corn. (b) Smut corn. (c) Cygnus Loop. (Images courtesy of (a) and (b) Dr. Michael W. Davidson, Florida State University, (c) NASA.)

Imaging in the Visible and Infrared Bands

The infrared band often is used in conjunction with visual imaging.

Figure 1.9 shows some examples of images obtained with a light microscope.

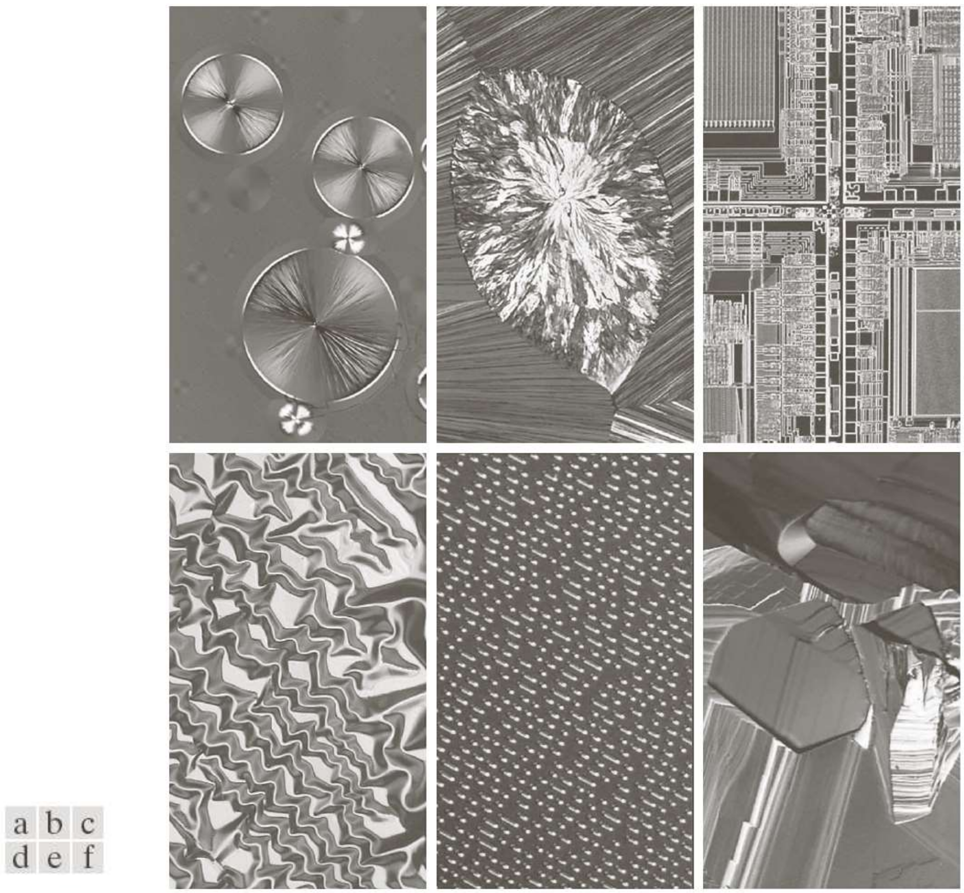


FIGURE 1.9 Examples of light microscopy images. (a) Taxol (anticancer agent), magnified 250×. (b) Cholesterol—40×. (c) Microprocessor—60×. (d) Nickel oxide thin film—600×. (e) Surface of audio CD—1750×. (f) Organic superconductor—450×. (Images courtesy of Dr. Michael W. Davidson, Florida State University.)

Another major area of visual processing is remote sensing, which includes several bands in the visual and infrared regions of the spectrum.

Table 1.1 shows the so-called thematic bands in NASA's LANDSAT satellite.

The primary function of LANDSAT is to obtain and transmit images of the Earth from space for purposes of monitoring environmental conditions of the planet.

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

TABLE 1.1 Thematic bands in NASA's LANDSAT satellite.

Figure 1.10 shows one image for each of the spectrum bands in Table 1.1.

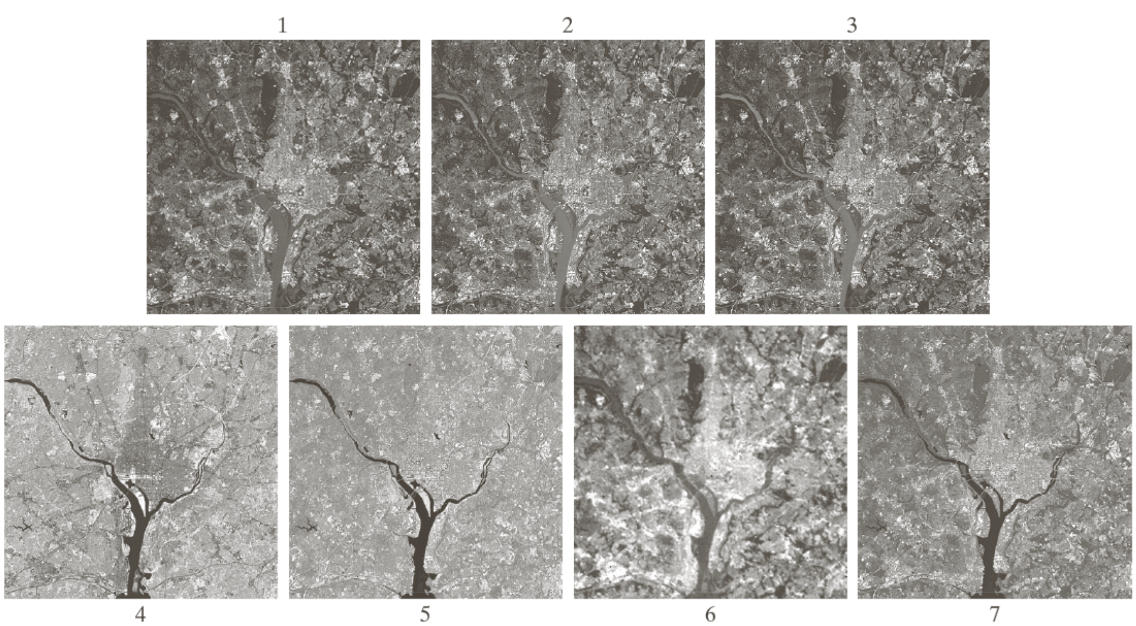


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Weather observation and prediction also are major applications of multi-spectrum imaging from satellites.

Figure 1.11 is an image of Hurricane Katrina.

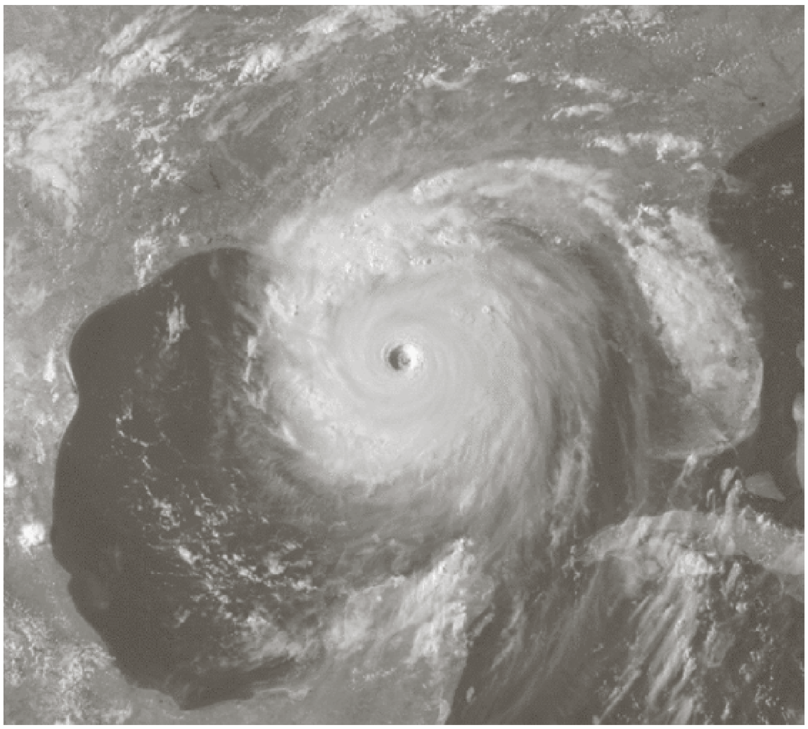


FIGURE 1.11 Satellite image of Hurricane Katrina taken on August 29, 2005. (Courtesy of NOAA.)

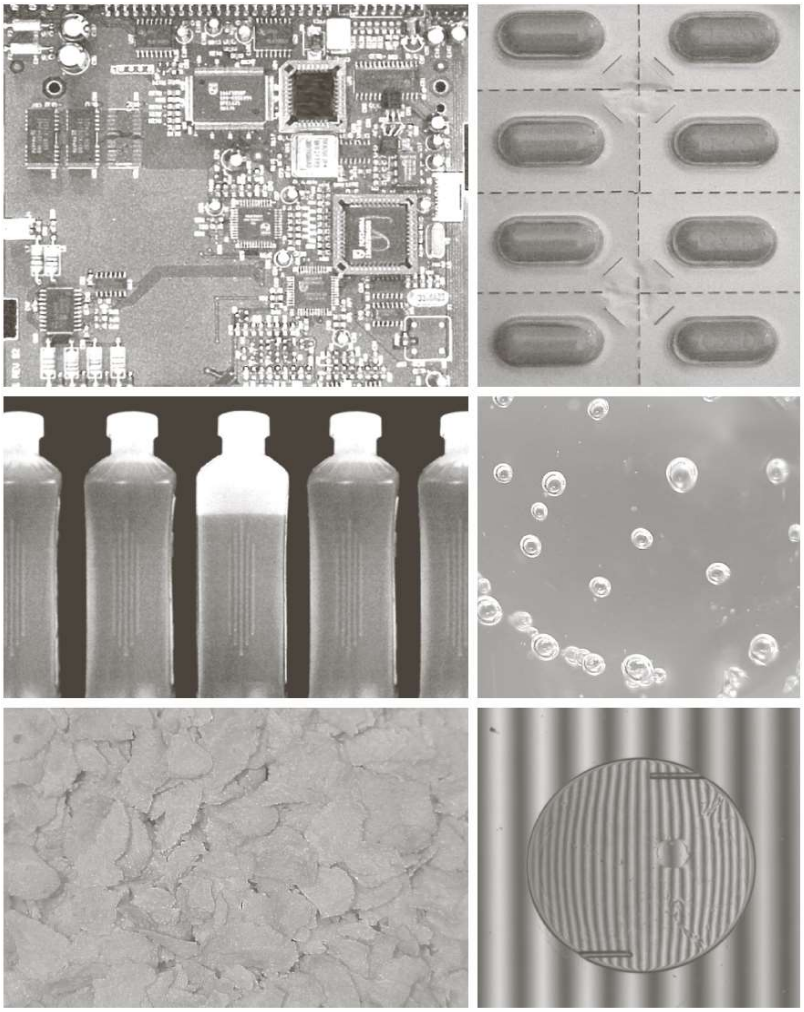
Figure 1.12 and Figure 1.13 show an application of infrared imaging. These images are part of the Nighttime Lights World data set, which provides a global inventory of human settlements.

FIGURE 1.12 Infrared satellite images of the Americas. The small gray map is provided for reference. (Courtesy of NOAA.)

FIGURE 1.13 Infrared satellite images of the remaining populated part of the world. The small gray map is provided for reference. (Courtesy of NOAA.)

A major area of imaging in the visual spectrum is in an automated visual inspection of manufactured goods.

Figure 1.14 shows some examples.



a	b
c	d
e	f

FIGURE 1.14 Some examples of manufactured goods often checked using digital image processing. (a) A circuit board controller. (b) Packaged pills. (c) Bottles. (d) Air bubbles in a clear-plastic product. (e) Cereal. (f) Image of intraocular implant. (Fig. (f) courtesy of Mr. Pete Sites, Perceptics Corporation.)

Figure 1.15 shows some additional examples of imaging in the visual spectrum.

a b
c
d

FIGURE 1.15 Some additional examples of imaging in the visual spectrum. (a) Thumb print. (b) Paper currency. (c) and (d) Automated license plate reading. (Figure (a) courtesy of the National Institute of Standards and Technology. Figures (c) and (d) courtesy of Dr. Juan Herrera, Perceptics Corporation.)

Imaging in the Microwave Band

The dominant application of imaging in the microwave band is radar. The unique feature of imaging radar is its ability to collect data over virtually any region at any time, regardless of weather or ambient lighting conditions.

Figure 1.16 shows a spaceborne radar image.

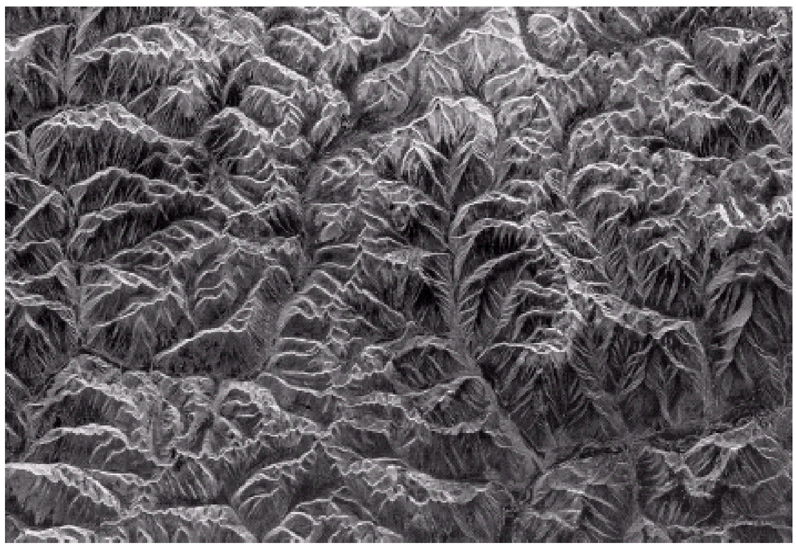


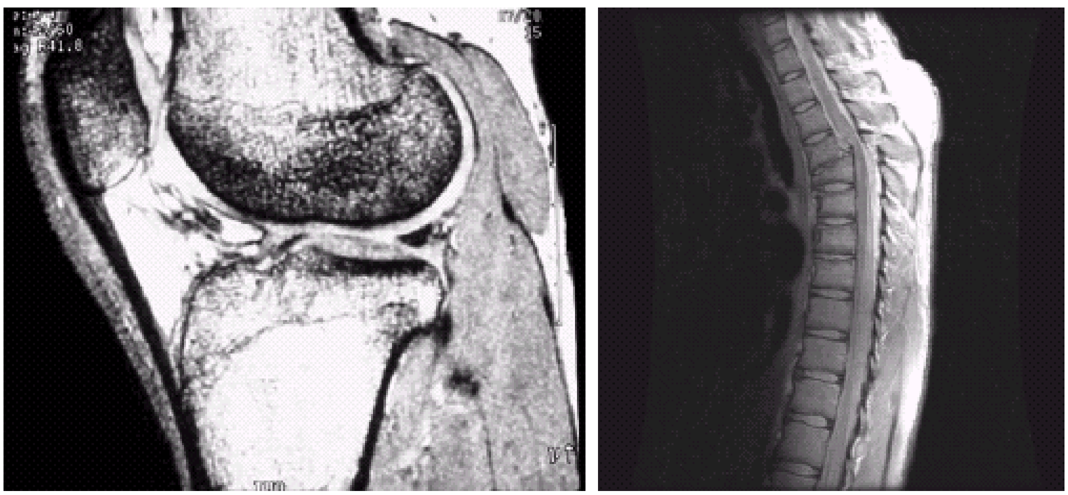
FIGURE 1.16 Spaceborne radar image of mountains in southeast Tibet. (Courtesy of NASA.)

Imaging in the Radio Band

The major applications of imaging in the radio band are in medicine and astronomy.

In medicine, radio waves are used in magnetic resonance imaging (MRI).

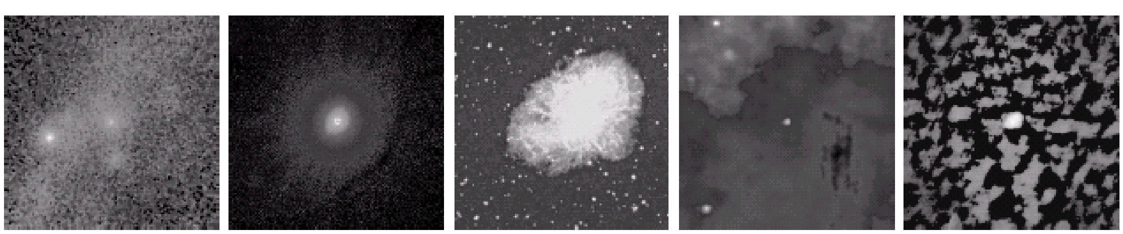
Figure 1.17 shows MRI images of a human knee and spine.



a b

FIGURE 1.17 MRI images of a human (a) knee, and (b) spine. (Image (a) courtesy of Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, and (b) Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

Figure 1.18 shows the images of the Crab Pulsar covering the electromagnetic spectrum.



Gamma X-ray Optical Infrared Radio

FIGURE 1.18 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

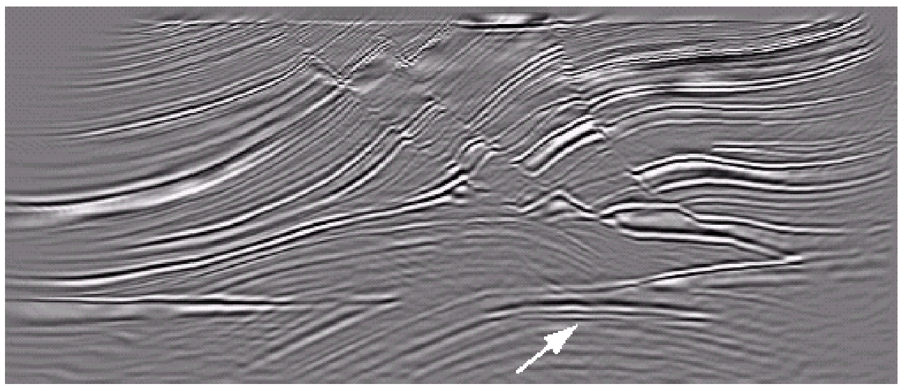
Examples in which Other Imaging Modalities Are Used

Although imaging in the EM spectrum is dominant by far, there are a number of other imaging modalities that also are important.

Imaging using "sound" finds application in geological exploration, industry, and medicine.

Figure 1.19 shows a cross-sectional image of a seismic model.

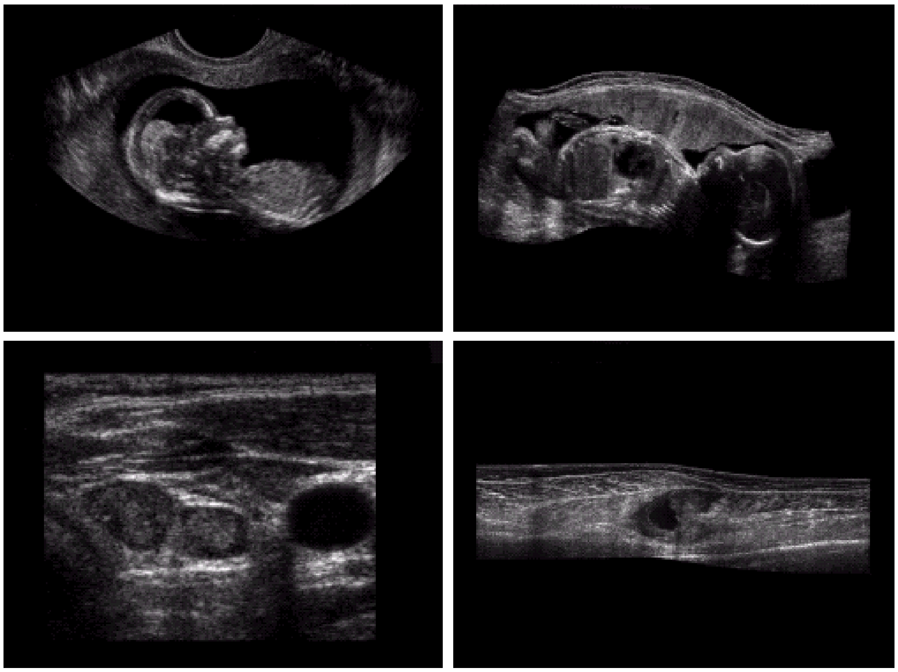
FIGURE 1.19 Cross-sectional image of a seismic model. The arrow points to a hydrocarbon (oil and/or gas) trap. (Courtesy of Dr. Curtis Ober, Sandia National Laboratories.)



In Figure 1.19, the arrow points to a hydrocarbon (oil and/or gas) trap. This target is brighter than the surrounding layers because the change in the target region is larger.

The best-known ultrasound imaging applications are in medicine, especially in obstetrics, where unborn babies are imaged to determine the health of their development.

Figure 1.20 shows some examples of ultrasound imaging.



a b
c d

FIGURE 1.20 Examples of ultrasound imaging. (a) Baby. (2) Another view of baby. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

1.4 Fundamental Steps in Digital Image Processing

Figure 1.23 shows a brief overview of the material in the textbook.

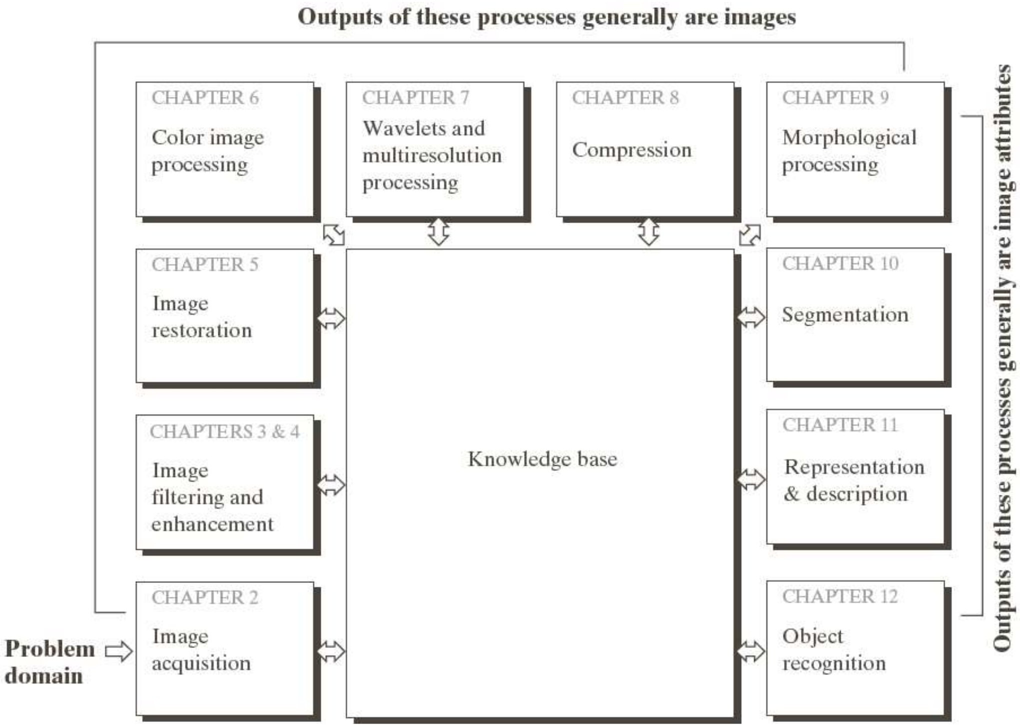


FIGURE 1.23 Fundamental steps in digital image processing. The chapter(s) indicated in the boxes is where the material described in the box is discussed.

1.5 Components of an Image Processing System

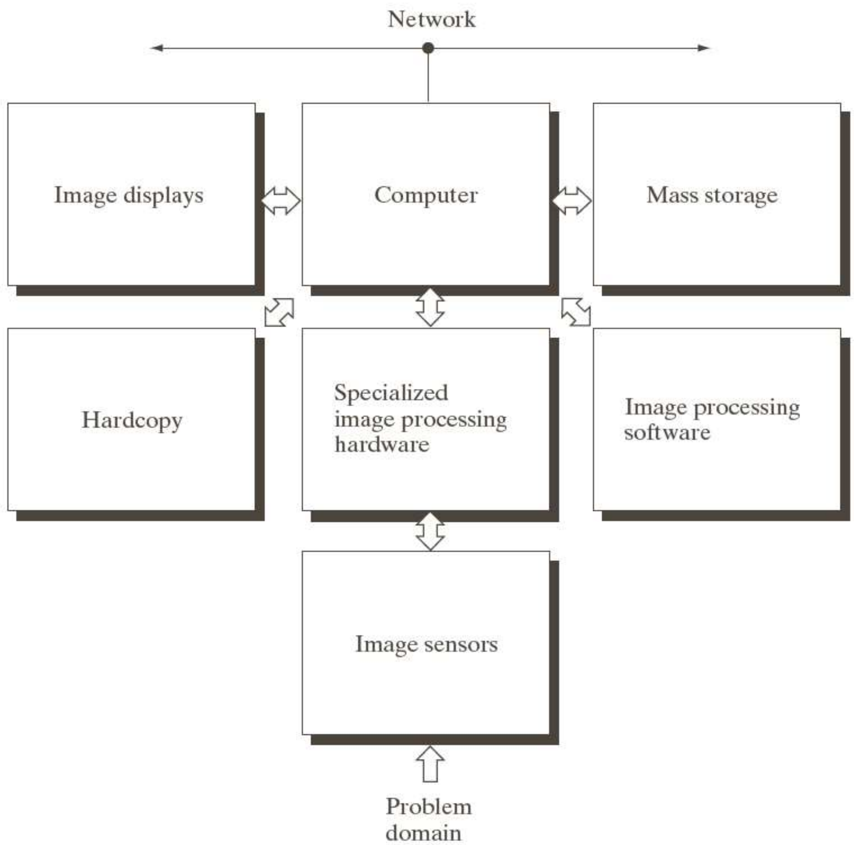


FIGURE 1.24 Components of a general-purpose image processing system.