Chapter 1. Introduction

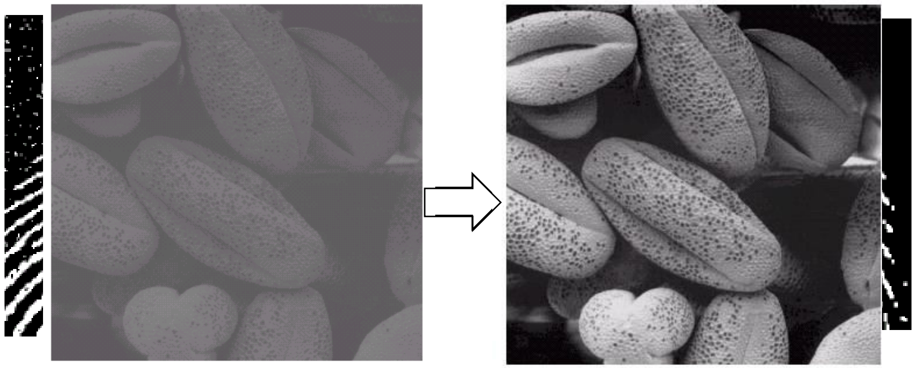
Introduction

One picture is worth more than ten thousand words.

Anonymous

Why digital image processing?

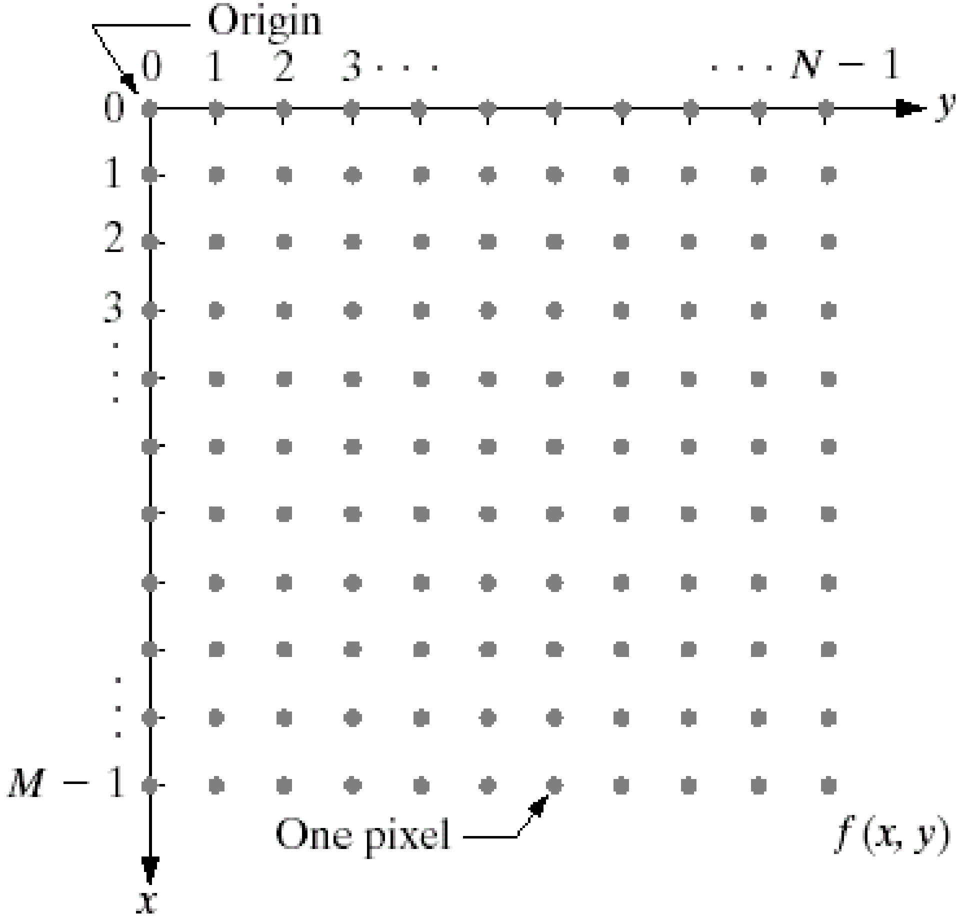
- Motivation
  - Improvement of pictorial information for **human interpretation**
  - Processing of image data for storage, transmission, and representation for **autonomous machine perception**



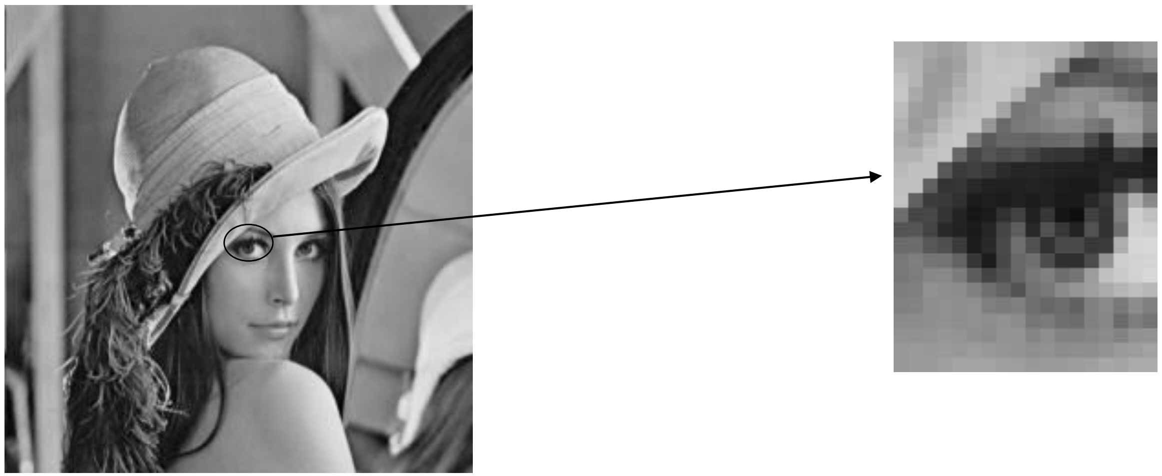
1.1 What is digital image?

- An image may be defined as a two-dimensional function $f(x, y)$, where (x, y) is a spatial coordinate,
  - $I = f(x, y)$
  - I: **intensity** (or **color**, **digital count**, **gray level**)
  - If (x, y) and I are finite and discrete quantities, I is called digital image
  - The element $I(i, j)$ in images is called **pixel**, **picture element**, and **image element**

Digital Image Representation



Pixels



Note: pixel is not a square!

Side story of Lena

1972 playboy: Miss Nov.

1997 Lena

Digital Image Representation

- Matrix form

$$\begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & f(0,1) & \dots & f(1,N-1) \\ & & \dots & \\ & & \dots & \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix}_{MxN}$$

bits to store the image = $M \times N \times k$
gray level = 2^k

1.2 Origins of Digital Image Processing

- One of the first applications of digital images was in **newspaper industry**, when pictures were sent by submarine cable between London and New York in early 1920s
- The figure was transmitted in this way and reproduced by Telegraph printer in 5 gray levels (halftone)

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

1.2 Origins of Digital Image Processing

- 15 gray 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.)

1.2 Origins of Digital Image Processing

- The first computers powerful enough to carry out image processing tasks appeared in the early 1960s
- The birth of what we call digital image processing today can be traced to the availability of those machines and to the begin of the space program during this period.
- The first picture of the moon by a U.S. spacecraft in 1964

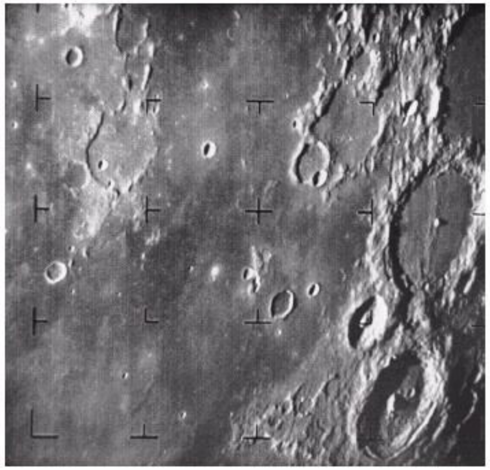


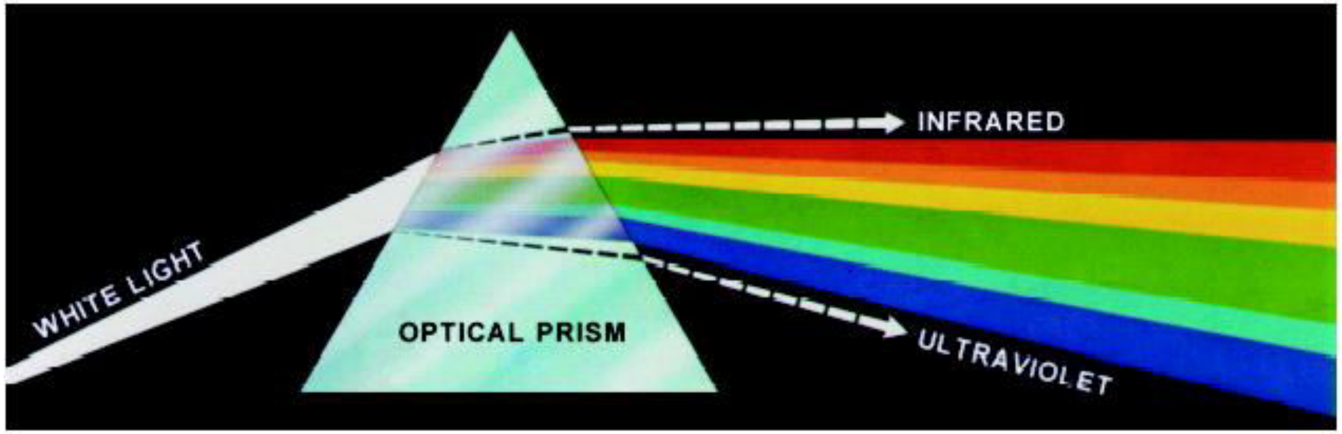
FIGURE 1.4 The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

1.3 Examples of Fields that Use Digital Image Processing

- Digital image processing has impact in some way on almost every area.
- One of the simplest ways to develop a basic understanding of the extent of IP applications is to categorize images according to their sources.
- Main sources of digital images
  - Electromagnetic (EM) energy spectrum
  - Ultrasound imaging
  - Synthetic (computer-generated) imaging

Electromagnetic (EM) Spectrum

- The light theorem was proposed by Newton (牛頓) in 1966, which said that white light consists of a continuous spectrum of colors ranging from violet to red.



Color spectrum seen by passing white light through a prim

Electromagnetic (EM) Spectrum

- Images based on radiation from the EM spectrum are the most familiar, especially images in visual bands of the spectral.
- EM waves can be conceptualized as propagating sin waves of varying wavelengths, or they can be though of as a steam of massless particles, each traveling in a wave-like pattern and moving at the speed of light.

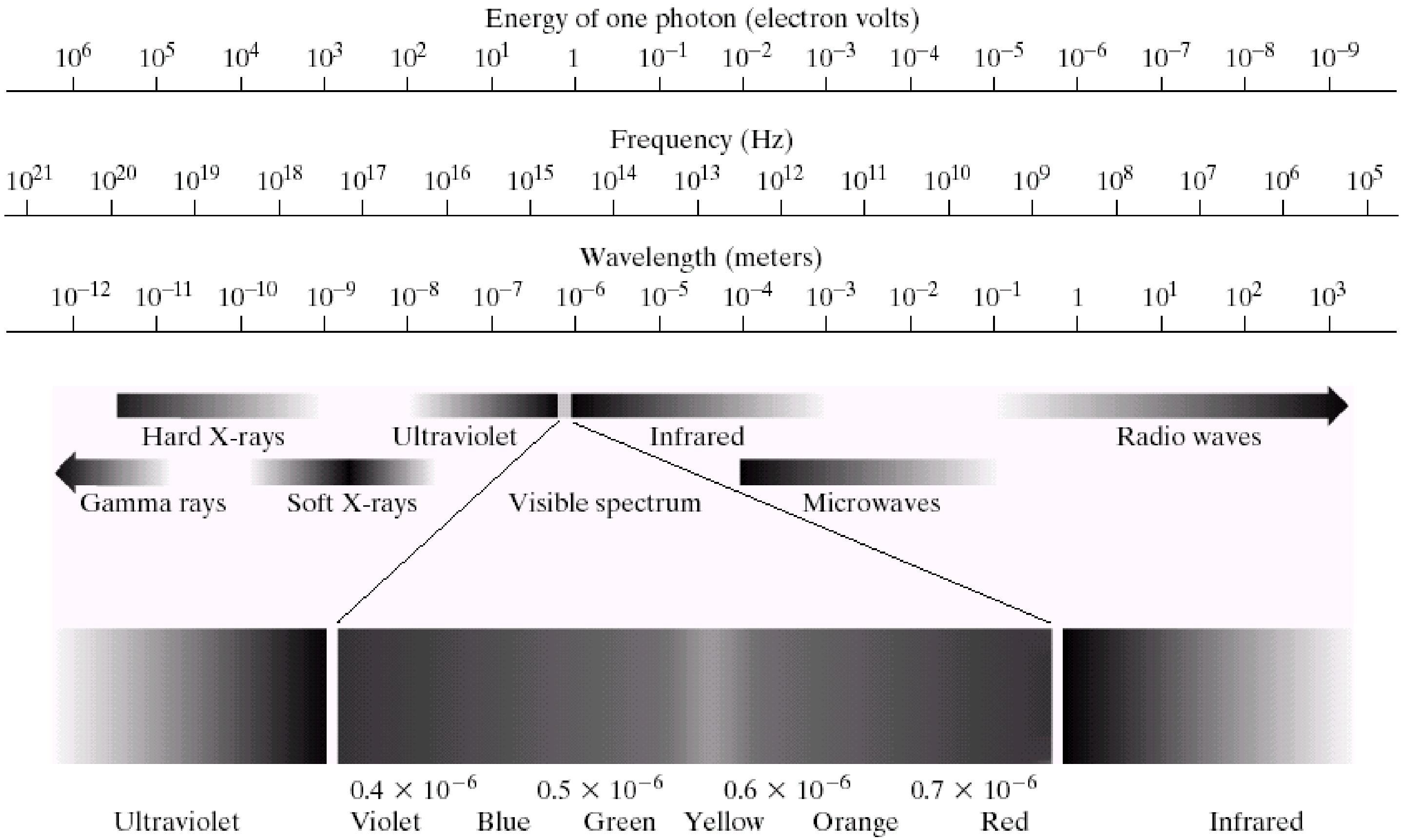
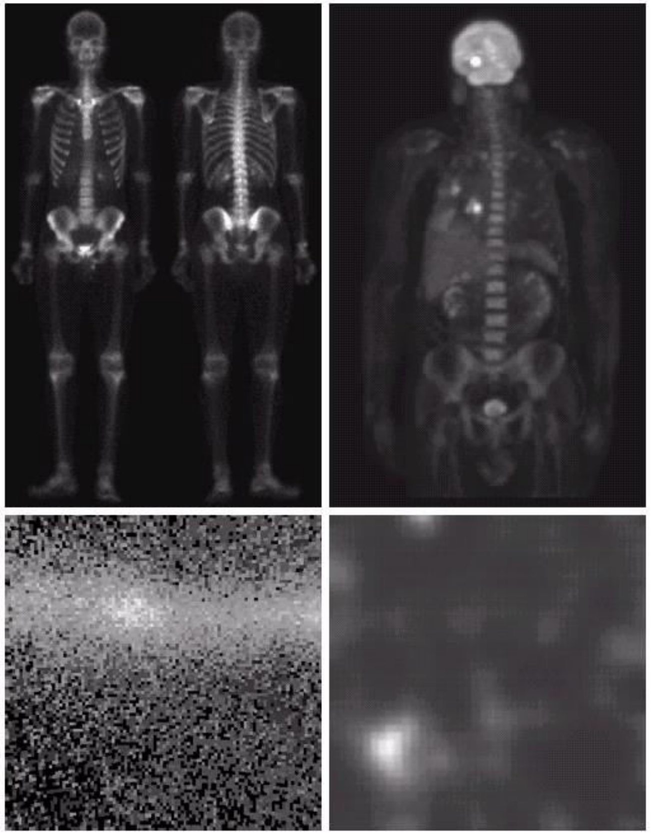


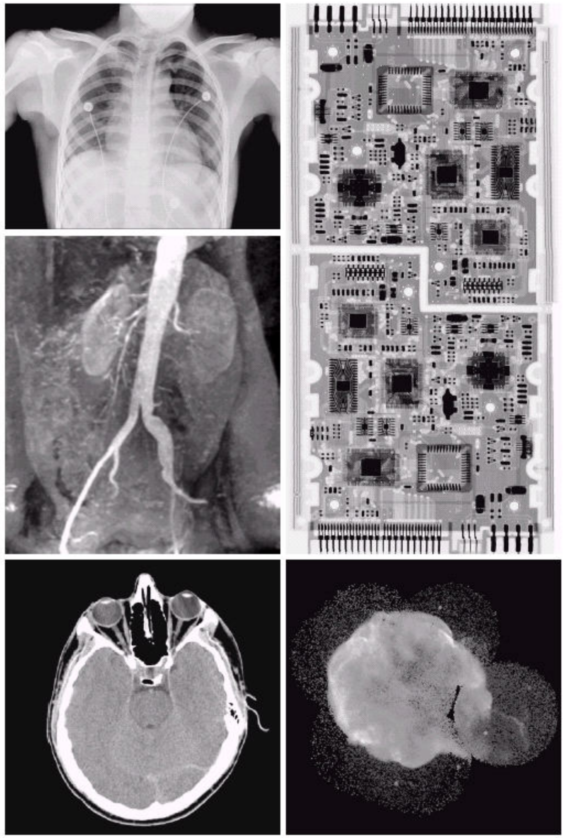
FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

1.3.1 Gamma-Ray Imaging



- Major uses of imaging based on gamma rays include nuclear medicine and astronomical observations (天文觀測).
- In nuclear medicine, inject a patient with radioactive isotope (放射性同位素) that emits gamma rays as it decays.
- Images, called positron emission tomography (PET,正子放射斷層攝影術), are produced from the emissions collected by gamma ray detectors.

1.3.2 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.)

- X-rays are the oldest sources of EM radiation used for imaging.
- The best known use of X-rays is medical diagnostics, but they also are used extensively in industry and other areas, such as astronomy.

1.3.4 Visible & Infrared Band: Remote Sensing

Landsat 7 ETM+ senor

Band No.	Name	Wavelength (μm)	Characteristics
1	Blue	0.44-0.51	Maximum water penetration
2	Green	0.52-0.60	Good for measuring plant vigor
3	Red	0.63-0.69	Vegetation discrimination
4	Infrared	0.77-0.90	Biomass and shoreline mapping
5	Shortwave infrared I	1.55-1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4-12.36	Soil moisture; thermal mapping
7	Shortwave infrared II	2.06-2.35	Mineral mapping

Applications of multispectral image: Land-cover classification, air quality monitoring (pm 10, pm 2.5), population prediction..etc

Remote Sensing: Multispectral Imaging

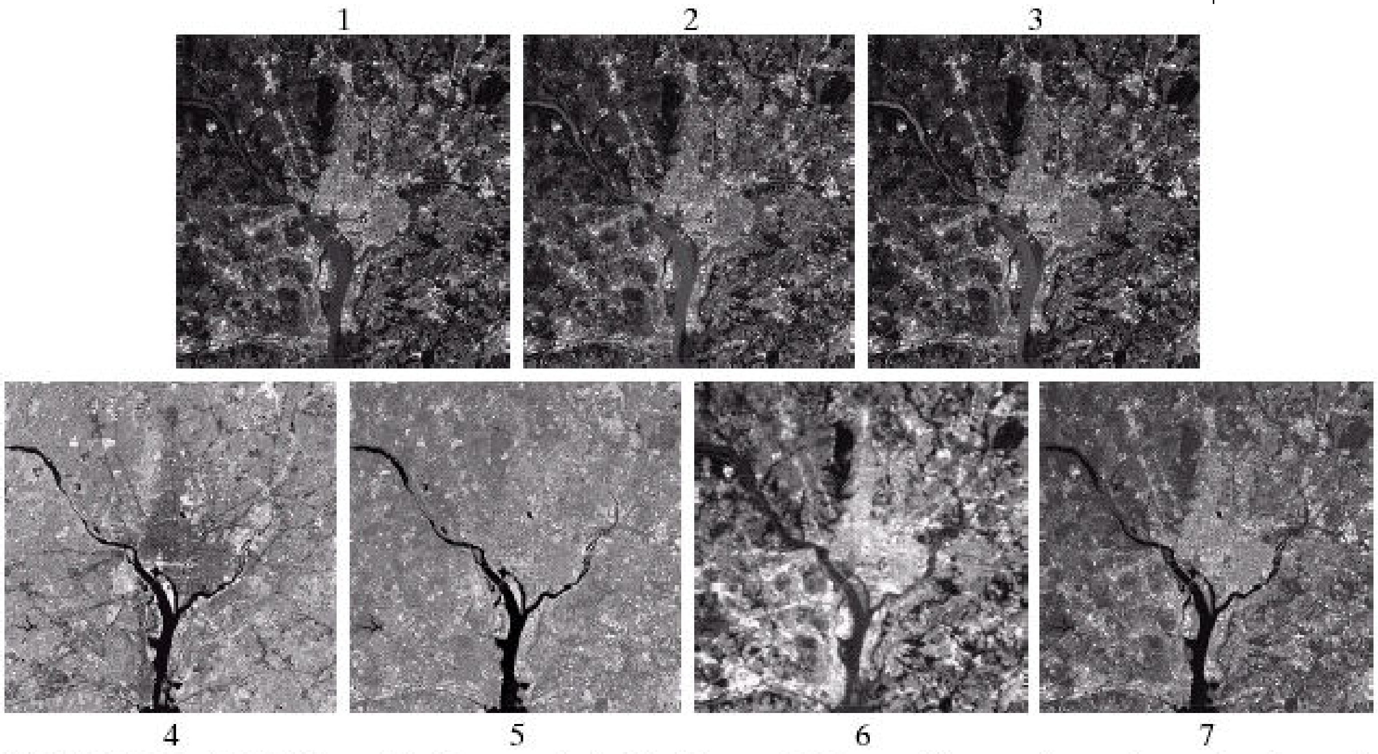


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

1.3.4 Visible & Infrared Band: Remote Sensing

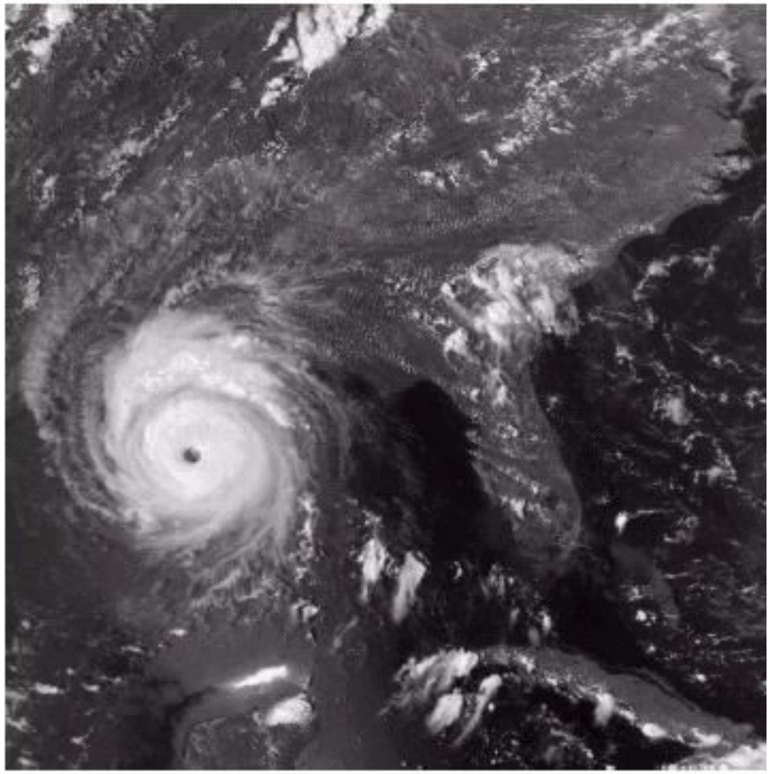
http://landsat.usgs.gov/best_spectral_bands_to_use.php

Landsat-7 ETM+ Bands (µm)			Landsat-8 OLI and *TIRS* Bands (µm)		
			30 m Coastal/Aerosol	0.435 - 0.451	Band 1
Band 1	30 m Blue	0.441 - 0.514	30 m Blue	0.452 - 0.512	Band 2
Band 2	30 m Green	0.519 - 0.601	30 m Green	0.533 - 0.590	Band 3
Band 3	30 m Red	0.631 - 0.692	30 m Red	0.636 - 0.673	Band 4
Band 4	30 m NIR	0.772 - 0.898	30 m NIR	0.851 - 0.879	Band 5
Band 5	30 m SWIR-1	1.547 - 1.749	30 m SWIR-1	1.566 - 1.651	Band 6
Band 6	60 m TIR	10.31 - 12.36	*100 m TIR-1*	*10.60 – 11.19*	Band 10
			100 m TIR-2	*11.50 – 12.51*	Band 11
Band 7	30 m SWIR-2	2.064 - 2.345	30 m SWIR-2	2.107 - 2.294	Band 7
Band 8	15 m Pan	0.515 - 0.896	15 m Pan	0.503 - 0.676	Band 8
			30 m Cirrus	1.363 - 1.384	Band 9

Characteristic features of Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

Band	Wavelength	Useful for mapping
Band 1 – coastal aerosol	0.43 - 0.45	coastal and aerosol studies
Band 2 – blue	0.45 - 0.51	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 3 - green	0.53 - 0.59	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - red	0.64 - 0.67	Discriminates vegetation slopes
Band 5 - Near Infrared (NIR)	0.85-0.88	Emphasizes biomass content and shorelines
Band 6 - Short-wave Infrared (SWIR) 1	1.57 - 1.65	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7 - Short-wave Infrared (SWIR) 2	2.11 - 2.29	Improved moisture content of soil and vegetation and thin cloud penetration
Band 8 - Panchromatic	0.50 - 0.68	15 meter resolution, sharper image definition
Band 9 – Cirrus	1.36 - 1.38	Improved detection of cirrus cloud contamination
Band 10 – TIRS 1	10.60 – 11.19	100 meter resolution, thermal mapping and estimated soil moisture
Band 11 – TIRS 2	11.5 - 12.51	100 meter resolution, Improved thermal mapping and estimated soil moisture

Multispectral Imaging



- Weather observation and prediction also are major applications. For instance, this is an image of Katrina hurricane, one of most devastating storms in recent memory in USA.
- This image was taken by a National Oceanographic and Atmospheric Administration (NOAA) satellite using sensors in the visual and infrared bands. The eye of the hurricane is clearly visible.

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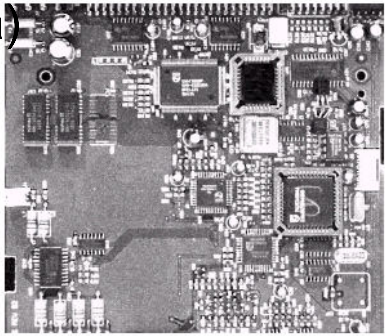
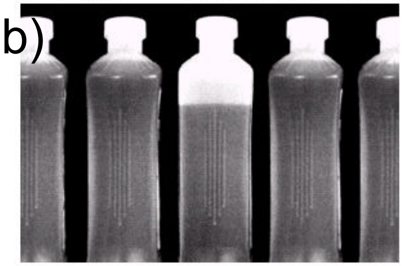
- The thermal band has the capability to observe faint sources of visible-near infrared emissions present on the Earth’s surface, including cities, towns, gas flares, and fires
- Images from 10~13.4 um wavelength band (thermal band)
- These images are parts of the **Nighttime Lights of the World** data sets, which provides a **global inventory of human settlements**.

Visual Spectrum: Automated Visual Inspection

(a)



(b)

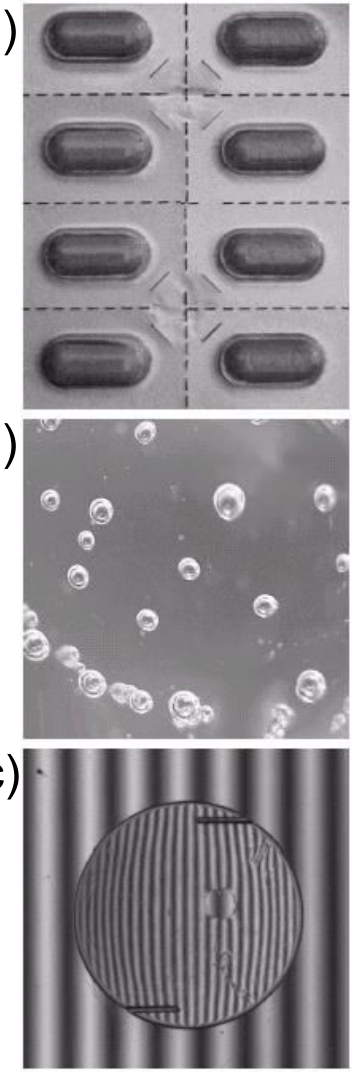


(c)

- Another major application of imaging in the visual spectrum is **automatic visual inspection of manufactured goods**.
- (a) is a controller board for a CD-ROM drive. A typical image processing task with products like this is to inspect them for missing pars.
- (b) shows an application in which image processing is used to look for bottles that are not filled up to an acceptable level.
- (c) shows a batch of cereal during inspection for color and the presence of anomalies such as burned flakes.

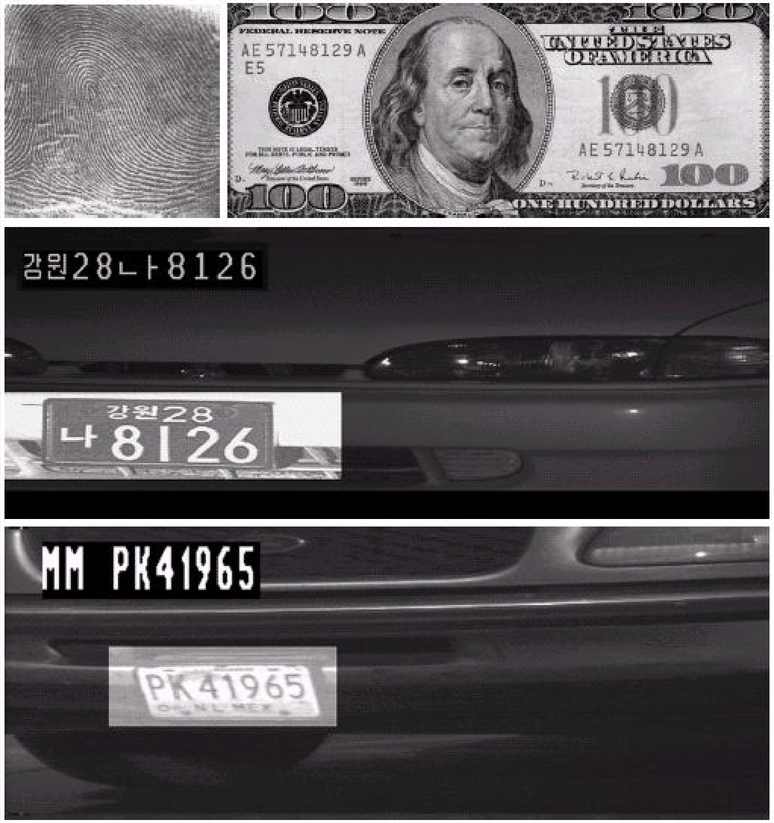
Visual Spectrum: Automated Visual Inspection

- (a) is an imaged pill container. The objective here is to have a machine look for missing pills.
- (b) shows a clear-plastic part with an unacceptable number of air pockets in it.
- (c) shows an image of an intraocular implant (replacement lens for the human eye). A "structured light" illumination technique was used to highlight for easier detection of lens deformation.



(a)
(b)
(c)

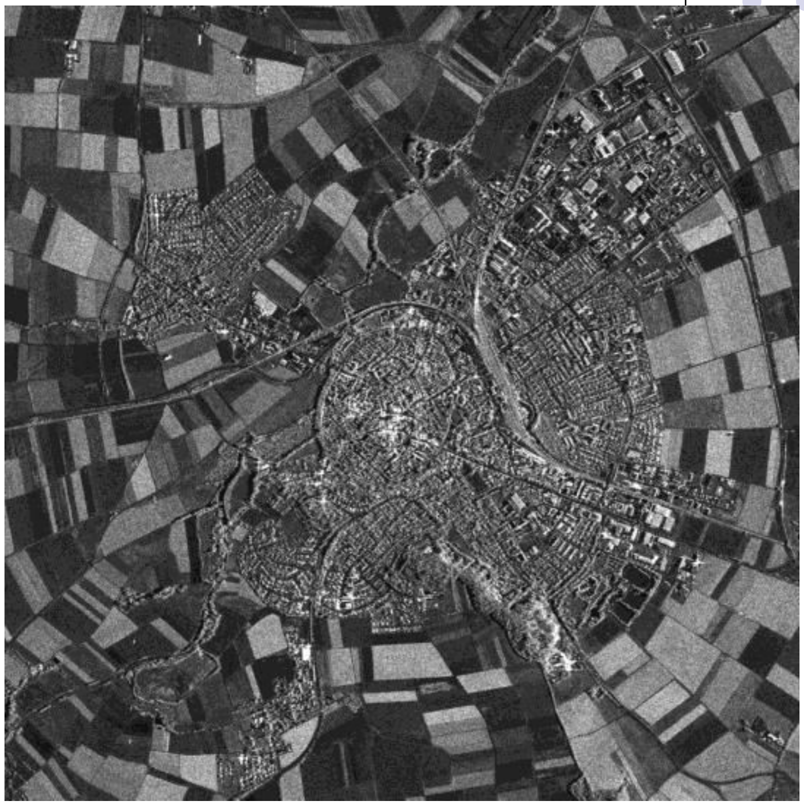
Visual Spectrum: Automated Visual Inspection



- (a)-1: Image of fingerprints. Enhance them or find features for searching for potential matches in the database.
- (a)-2”: Image of paper currency. Automated counting and reading the serial number for the purpose of tracking and identifying bills.
- (b), (c): Automatic license plate reading. The black rectangles show the results of reading

1.3.5 Imaging in Microwave Band: Radar

- Synthetic Aperture Radar (**SAR**) is a form of radar which is used to create images of 2D/3D objects, such as landscapes.
- Differential interferometry SAR(D-InSAR) requires taking at least two images. D-InSAR has the ability to generate and detect .



1.3.6 Imaging in 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). This technique places a patient in a powerful magnet and passes radio waves through his/her body in short pulses. Each pulse causes a responding pulse of radio waves to be emitted by the patient's tissues.

Human knee

Human spine

1.3.6 Imaging in Radio Band

- The images of the same region and object but taken in most of the bands discussed earlier. Each image gives a totally different "view" of the Crab Pulsar (蟹狀星雲).

Gamma X-ray Optical Infrared Radio

1.3 Ultrasound Imaging

- The best known applications of this technique are in medicine, especially in obstetrics (醫學產科), where unborn babies are imaged to determine the health of their development.

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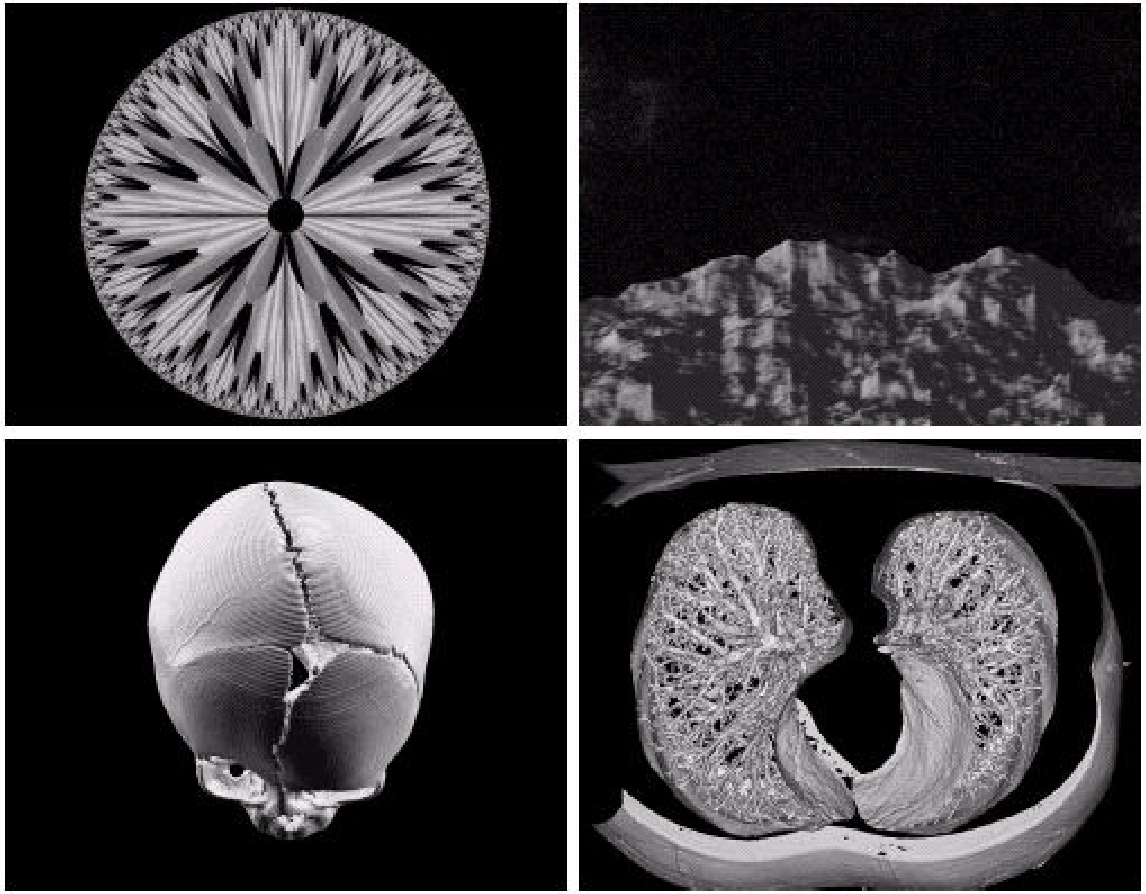
1.3 Ultrasound Imaging

- The basic procedure:
  - The ultrasound system transmit high-frequency sound pulses into the body.
  - The sound waves travel into the body and hit a boundary between tissues. Some of the sound waves are reflected back to the probe, while some sound waves travel on further places until they reach another boundary and get reflected.
  - The reflected waves are picked up by the probe, and the signals are relayed to the computer.
  - The machine calculates the distance from the probe to the tissues or organ boundaries using the speed of sound in tissue (1540 m/s) and the time of each echo's return.
  - The system displays the distances and intensities of the echoes on the screen, forming a 2D image.

1.3 Synthetic imaging

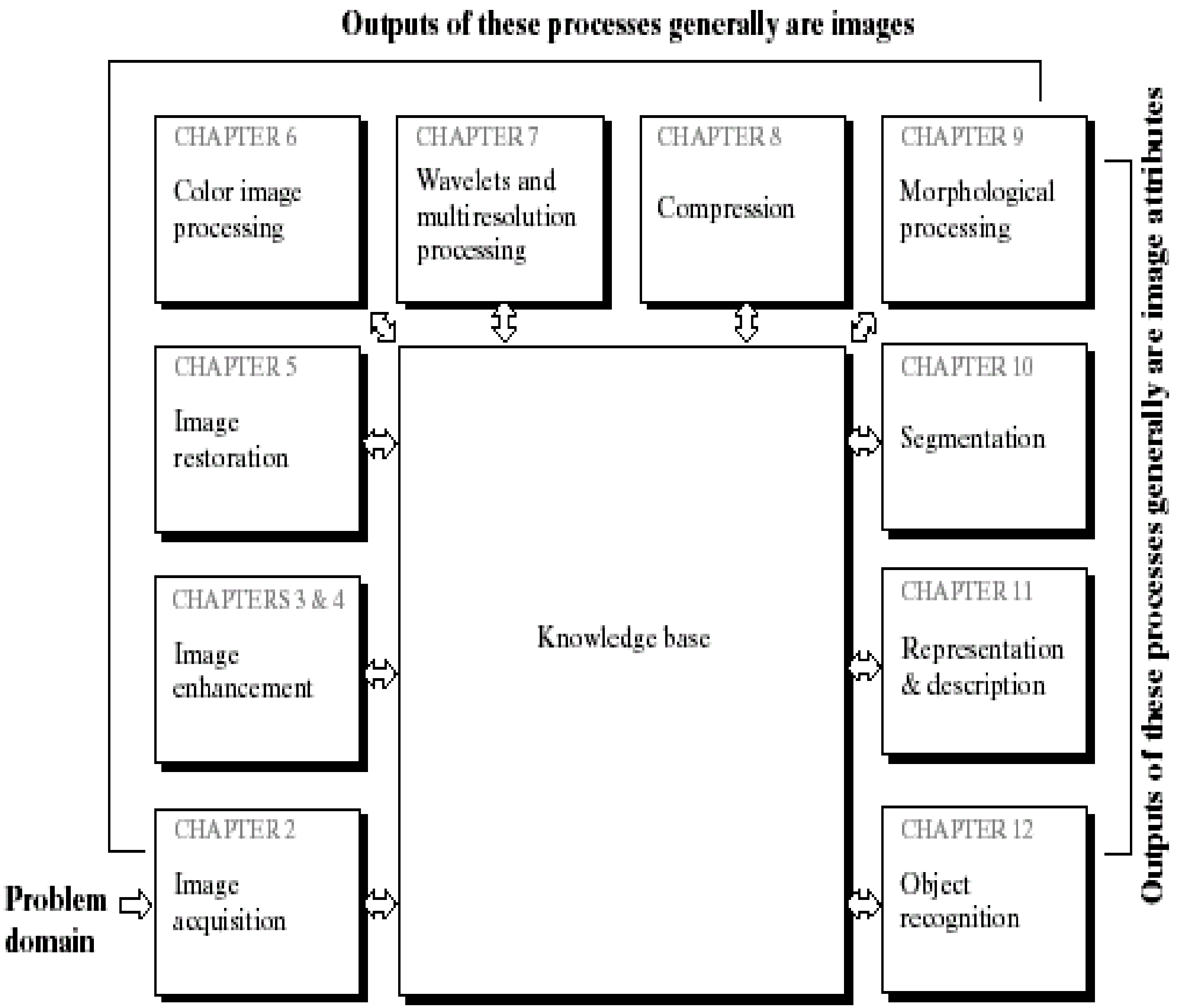


a b
c d

FIGURE 1.22 (a) and (b) Fractal images. (c) and (d) Images generated from 3-D computer models of the objects shown. (Figures (a) and (b) courtesy of Ms. Melissa D. Binde, Swarthmore College, (c) and (d) courtesy of NASA.)

1.3 Synthetic imaging

1.4 Fundamental Steps in DIP



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1.4 Fundamental Steps in DIP

- **Image acquisition** (Chap. 2)
  - Could be as simple as being given an image that is already in digital form
  - Generally, this stage involves preprocessing
- **Image enhancement** (Chaps. 3 and 4)
  - **Bring out detail** that is obscured, or simply to **highlight certain features of interest** in an image
  - Based on **human subjective preferences** regarding what constitutes a "good" enhancement

1.4 Fundamental Steps in DIP

- **Image restoration** (Chap. 5)
  - Improve the appearance of an image
  - Objective: **tend to be based on mathematical or probabilistic models of image degradation**
- **Color image processing** (Chap. 6)
  - **Color models**
  - Color processing in a digital domain
- **Wavelets** (Chap. 7)
  - **Represent images in various degrees of resolution**
  - in this book: image compression & pyramidal representation
  - Skip this chapter.

1.4 Fundamental Steps in DIP

- **Compression** (Chap. 8)
  - **Reduce the storage required to save an image**
  - Reduce the bandwidth required to transmit it
- **Morphological processing** (Chap. 9)
  - **Extract image components** that are useful in the representation and description of shape
  - Output: image attributes
- **Segmentation** (Chap. 10)
  - **Partition an image into several components/objects**
  - Automatic segmentation is one of the most difficult tasks in digital image processing

1.4 Fundamental Steps in DIP

- **Representation & Description** (Chap. 11)
  - Always follow the segmentation stage
  - Determine boundary representation or regional representation
  - Description (feature selection)
    - Extracting attributes that result in some quantitative information of interest or are basic for differentiating one class of objects from another
- **Recognition/Classification** (Chap. 12)
  - Assigns a label to an object based on its descriptors

Image Processing Level

- **Low-level processing**
  - Inputs and outputs are images
  - Primitive operations: de-noise, enhancement, sharpening, ⋯
- **Mid-level processing**
  - Inputs are images, outputs are **attributes** extracted from images
  - Segmentation, classification,⋯
- **High-level processing**
  - **"Make sense"** of an ensemble of recognized objects by machines

Research fields