CHAPTER 1

INTRODUCTION TO DIGITAL IMAGE PROCESSING

CHAPTER 1: INTRODUCTION

- **Interest in DIP methods stem from 2 principal applications:**
  - **Improvement of pictorial information for human interpretation**
  - **Processing of image data for storage, transmission, and representation for autonomous machine perception.**
- **What is a digital image?**
  - ***f*(*x*,*y*), *x*&*y*: spatial plane coordinates, *f*(*x*,*y*): intensity**
  - ***x*,*y*, and *f*(*x*,*y*): finite, discrete quantities**
  - **picture elements, image elements, pels, pixels.**
  - **Humans: limited to the visual band of EM spectrum.**
  - **Imaging machines: cover the entire spectrum.**
  - **Scope of image processing**
    - **Both I and O are images?**
    - **Includes computer vision?**
    - **Image analysis is between image processing and computer vision**
  - **Low-level (I&O: images) process, mid-level (I: image, O: extracted attributes) process, high-level process.**

BARTLANE CABLE PICTURE TRANSMISSION SYSTEM

- **Early 1920s: Bartlane cable picture transmission system**
  - **Reduced the time required to transport a picture across the Atlantic from more than a week to less than three hours.**
  - **Pictures were coded for cable transmission and then reconstructed at the receiving end on a telegraph printer fitted with type faces simulating a halftone pattern.**
  - **The early Bartlane systems were capable of coding images in five distinct brightness levels. This was increased to fifteen levels in 1929.**

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

MORE TRANSATLANTIC TRANSMISSIONS IN 1920'S

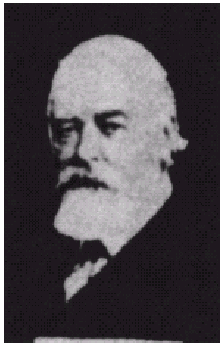


FIGURE 1.2 A digital picture made in 1922 from a tape punched after the signals had crossed the Atlantic twice. Some errors are visible. (McFarlane.)

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

OTHER HISTORICAL DEVELOPMENTS

- 1964: Pictures of the moon transmitted by Ranger 7 were processed by a computer at the Jet Propulsion Lab to correct various types of image distortion inherent in the on-board TV camera.
- Experience with Ranger 7 led to an improvement in image enhancement and restoration in other projects.
  - Surveyor missions to the moon
  - Mariner series of flyby missions to Mars
  - Apollo manned flights to the moon

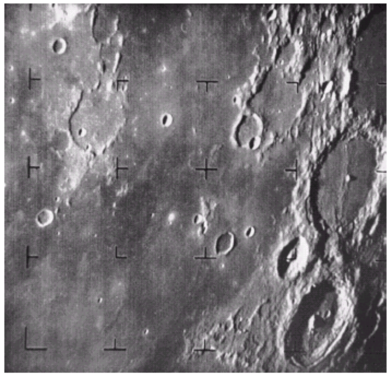


FIGURE 1.4 The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

APPLICATIONS OF IMAGE PROCESSING

- Early 1970's: Invention of computerized axial tomography
- Applications of image processing
  - For human interpretation
    - Geography
    - Archeology.
    - Physics
    - Astronomy
    - Biology
    - Nuclear medicine
    - Law enforcement
    - Defense
  - For machine perception
    - Automatic character recognition
    - Industrial machine vision for product assembly and inspection
    - Military recognizance
    - Automatic processing of fingerprints
    - Screening of X-rays and blood samples
    - Machine processing of aerial and satellite imagery for weather prediction and environment assessment

ENERGY SOURCES FOR IMAGES

- Electromagnetic energy spectrum: Principal source of energy
  - The full range of frequencies, from radio waves to gamma rays, that characterizes light.
  - Gamma rays: highest energy, shortest wavelength
  - Radio waves: lowest energy, longest wavelength
- Electromagnetic radiation can be described in terms of a stream of photons, each traveling in a wave-like pattern, moving at the speed of light and carrying some amount of energy.
- The amount of energy a photon has makes it sometimes behave more like a wave and sometimes more like a particle. This is called the "wave-particle duality" of light.
- Low energy photons (such as radio) behave more like waves, while higher energy photons (such as X-rays) behave more like particles.
- Other sources of energy: acoustic, ultrasonic, electronic

ELECTROMAGNETIC SPECTRUM

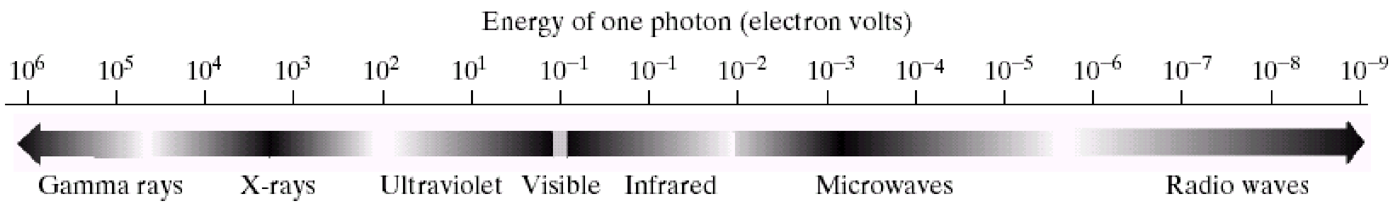


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

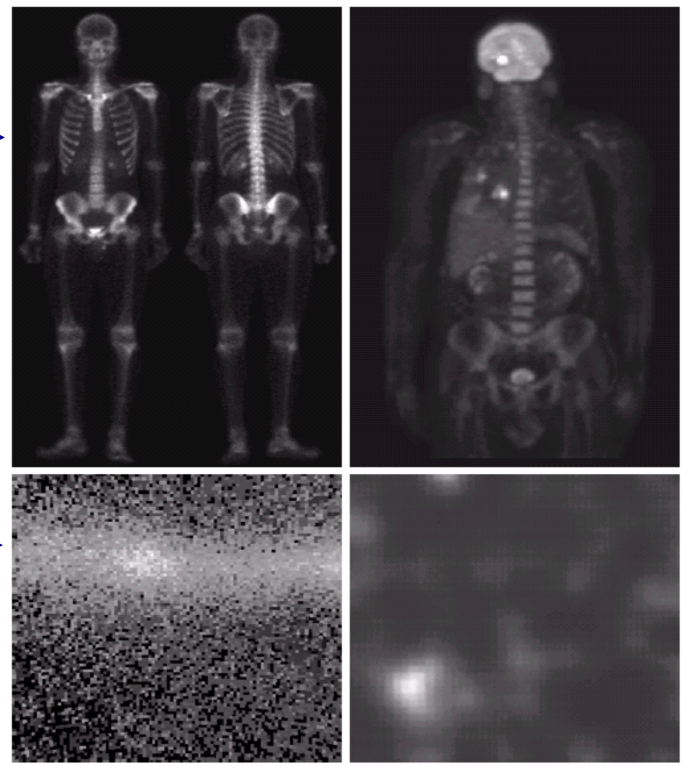
GAMMA-RAY

Major uses: Nuclear medicine & astronomical observations

Bone scan: locates sites of bone pathology

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.)



PET: another major modality of nuclear imaging

One sample of a sequence that constitutes a 3d rendition of the patient.

A star in the constellation Cygnus exploded about 15K years ago.

The superheated stationary gas cloud (Cygnus Loop) glows in a spectacular array of colors.

Gamma radiation from a valve in a nuclear reactor

X-RAY

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

Major uses: Medical diagnostics, astronomy, angiography, CAT scans

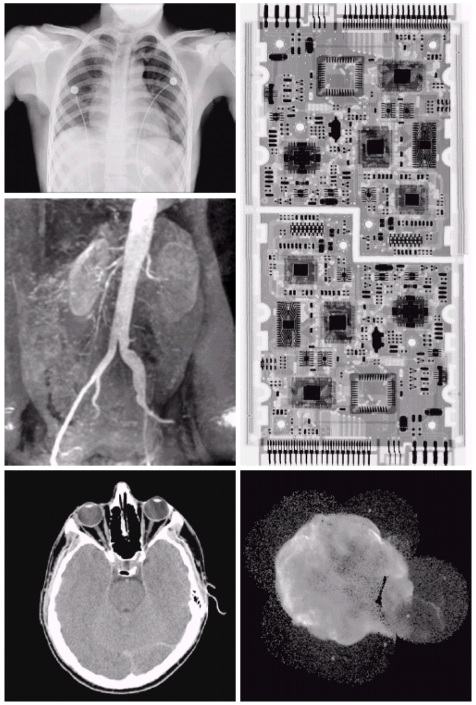


FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical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

ULTRAVIOLET

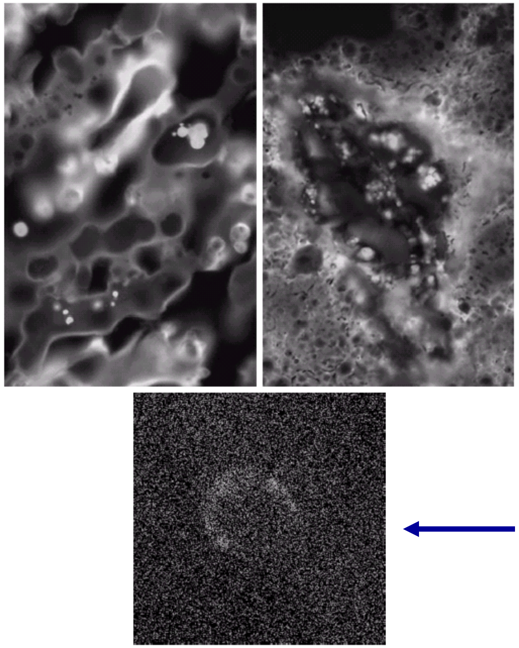
Major uses: lithography, industrial inspection, microscopy, lasers, biological imaging, astronomical observations.

Fluorescence is a phenomenon discovered in the middle of 19th century.

Fluorescence microscopy is a excellent method for studying materials that can be made to fluoresce (either in natural form or when treated with chemicals capable of fluorescing).

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.)



Fluorescence microscope image of normal corn

Corn infected by "smut," a disease of cereals, corn, etc.

Cygnus Loop imaged in the high-energy region of the ultraviolet band.

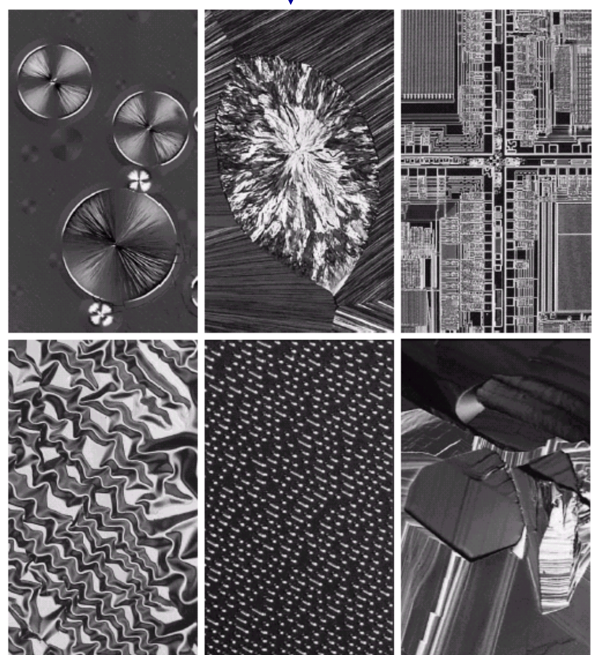
VISIBLE AND INFRARED – LIGHT MICROSCOPE

Major uses: light microscopy, astronomy, remote sensing, industry, law enforcement.

Cholesterol

Taxol (anticancer agent)

Microprocessor



Nickel oxide thin film

Surface of audio CD

Organic superconductor

a b c
d e f

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.)

VISIBLE AND INFRARED – REMOTE SENSING

TABLE 1.1 Thematic bands in NASA's LANDSAT satellite.

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

Remote sensing: usually includes several bands in the visual and infrared regions.

LANDSAT obtains and transmits images of the Earth from space, for purposes of monitoring environmental conditions.

Multispectral imaging:

One image for each band in the above table.

The differences between visual and infrared image features are quite noticeable.

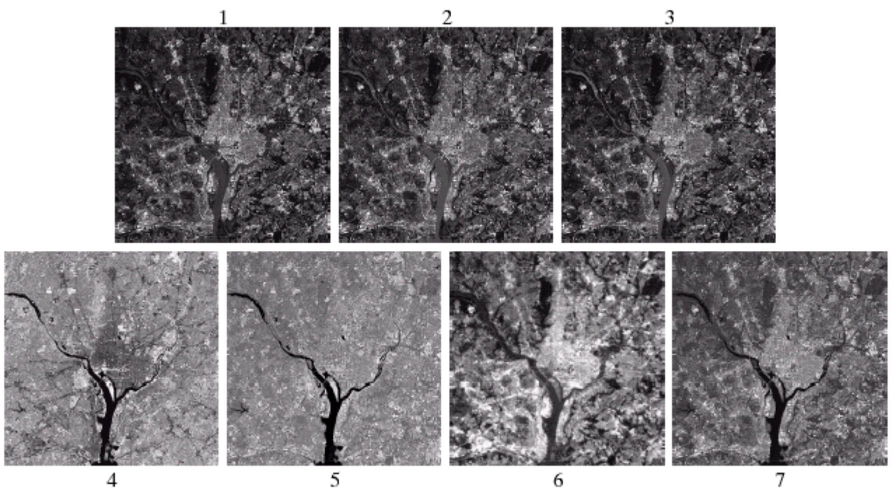


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

VISIBLE AND INFRARED – WEATHER OBSERVATION AND PREDICTION

An image of a hurricane taken by a satellite using sensors in the visible and infrared bands.

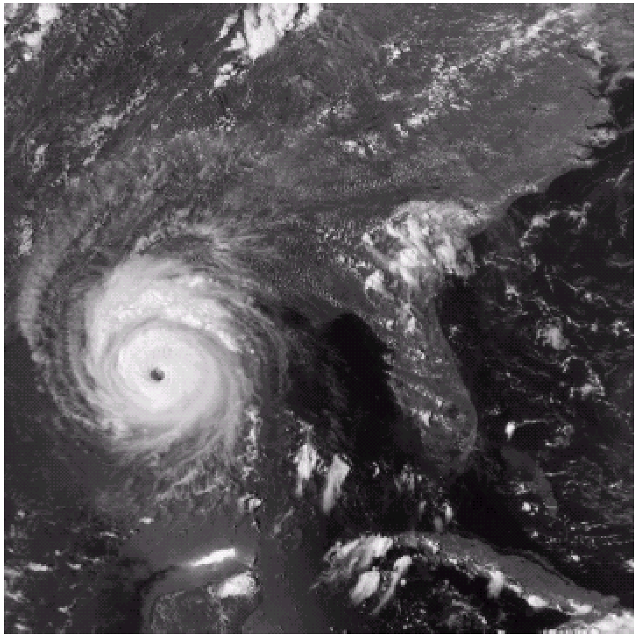
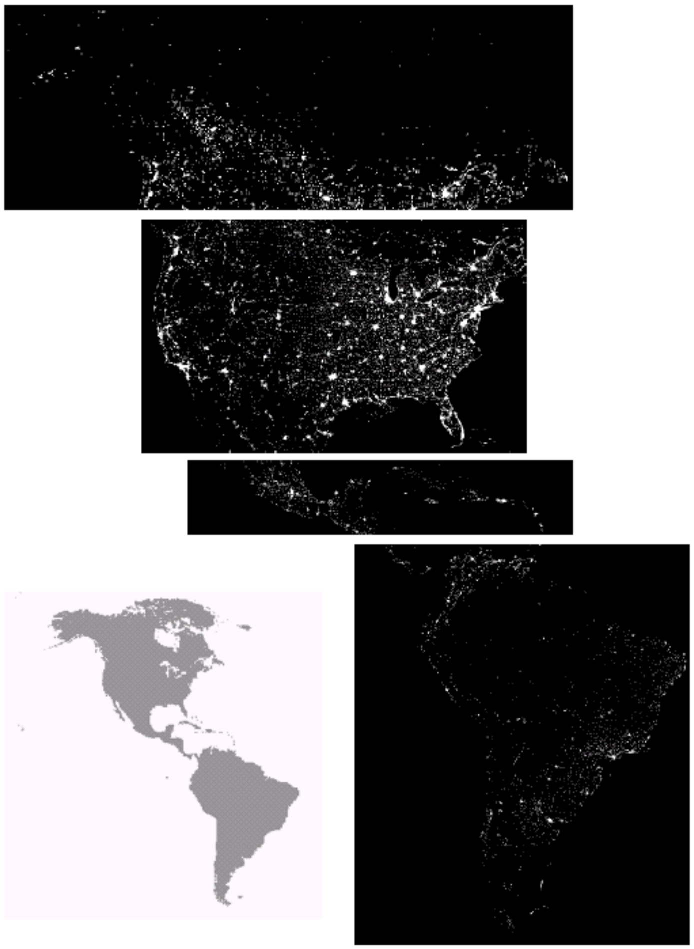


FIGURE 1.11 Multispectral image of Hurricane Andrew taken by NOAA GEOS (Geostationary Environmental Operational Satellite) sensors. (Courtesy of NOAA.)

INFRARED – HUMAN SETTLEMENTS (THE AMERICAS)

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



These images are part of Nighttime Lights of the World data set.

This set provides a global inventory of human settlements.

INFRARED – HUMAN SETTLEMENTS (OTHER PARTS)

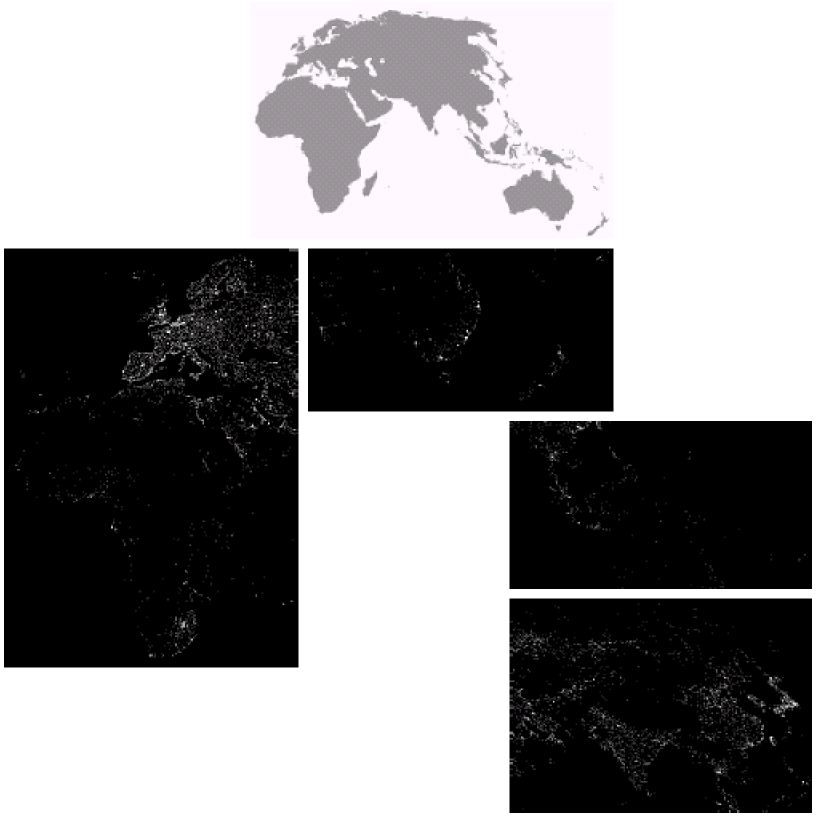
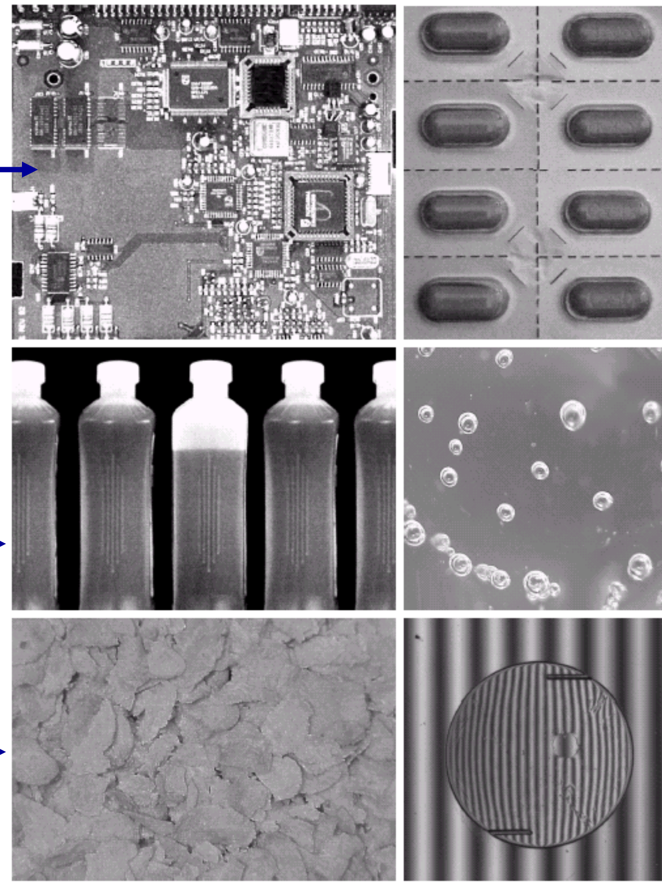


FIGURE 1.13 Infrared satellite images of the remaining populated part of the world. The small gray map is provided for reference. (Courtesy of NOAA.)

VISIBLE – AUTOMATED VISUAL INSPECTION OF MANUFACTURED GOODS

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) Bubbles in clear-plastic product. (e) Cereal. (f) Image of intraocular implant. (Fig. (f) courtesy of Mr. Pete Sites, Perceptics Corporation.)



A circuit board controller (the back square is a missing component)

Pill container

A bottle that is not filled up to an acceptable level.

A clear plastic part with an unacceptable number of air pockets.

A batch of cereal inspected for color and the presence of anomalies such as burned flakes.

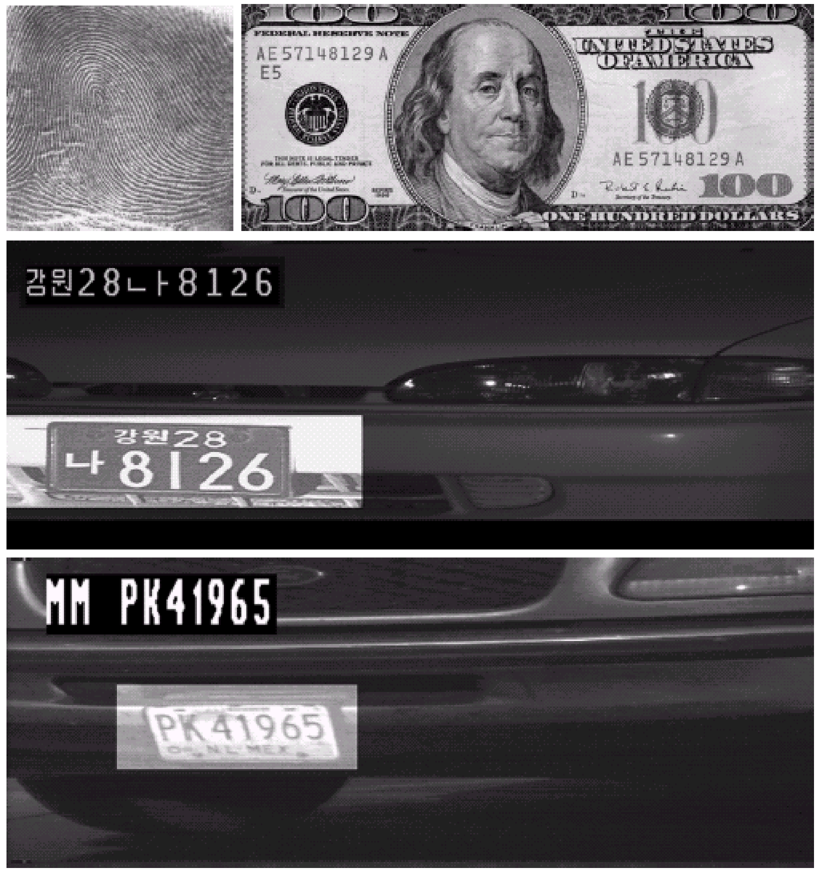
An intraocular implant (replacement lens for the human eye)

VISIBLE – OTHER APPLICATIONS

A thumb print

Paper currency

Automated license plate reading

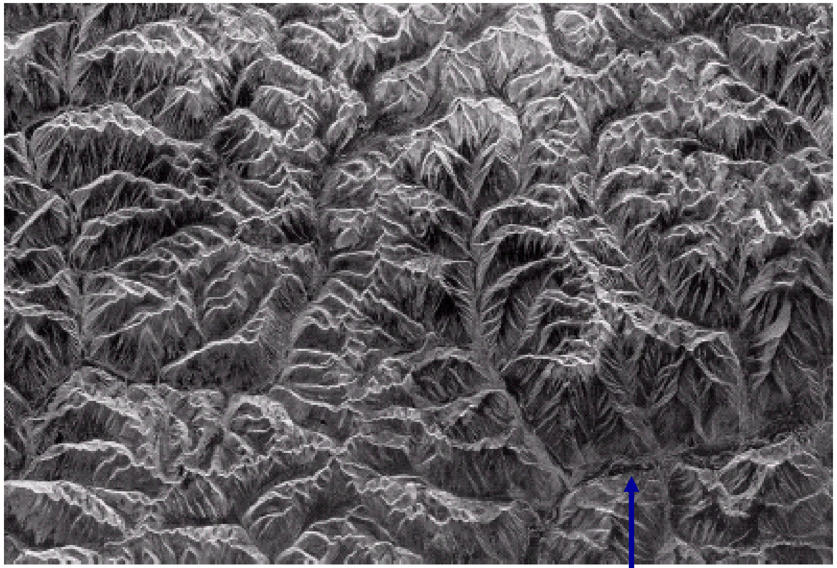


a b
c
d

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.)

MICROWAVE – IMAGING RADAR

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



Lhasa River

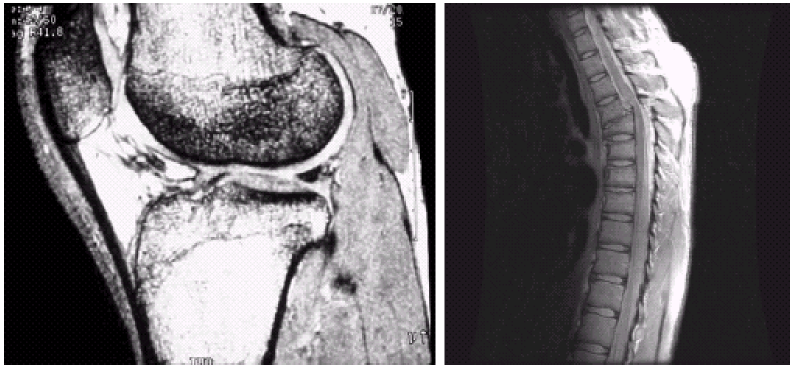
Imaging radar

- **has the unique ability to collect data over virtually any region at any time, regardless of weather or ambient lightning conditions.**
- **Works like a flash camera with its own illumination.**
- **Uses an antenna and digital computer processing to record images.**

Note the clarity and detail of the image, unencumbered by clouds or other atmospheric conditions that normally interfere with image in the visual band!

RADIO – MRI

Major uses: medicine and astronomy



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.)

Magnetic resonance imaging (MRI):

- **places a patient in a powerful magnet and passes radio waves through the body in short pulses.**
- **each pulse causes a responding pulse of radio waves to be emitted by the patient's tissues.**
- **produces a 2D picture of section of the patient.**

CRAB PULSAR IMAGES

In the summer of 1054 A.D., Chinese astronomers reported that a star in the constellation of Taurus suddenly became as bright as the full Moon. Fading slowly, it remained visible for over a year. It is now understood that a spectacular supernova explosion - the detonation of a massive star whose remains are now visible as the Crab Nebula - was responsible for the apparition. The core of the star collapsed to form a rotating neutron star or pulsar, one of the most exotic objects known to 20th century astronomy. Like a cosmic lighthouse, the rotating Crab pulsar generates beams of radio, visible, x-ray and gamma-ray energy which, as the name suggests, produce pulses as they sweep across our view.

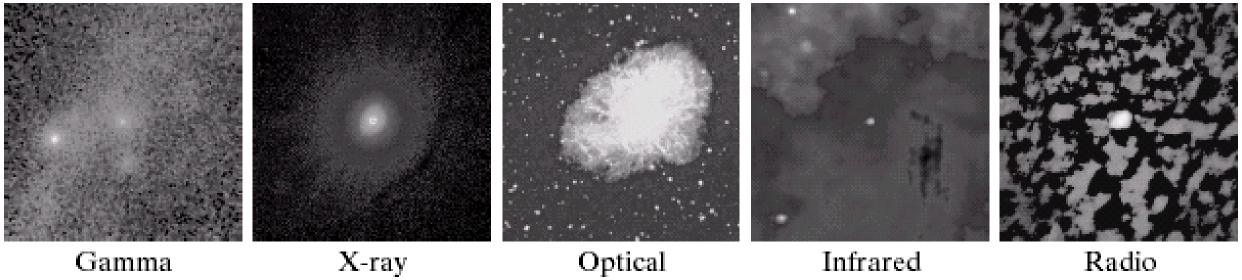


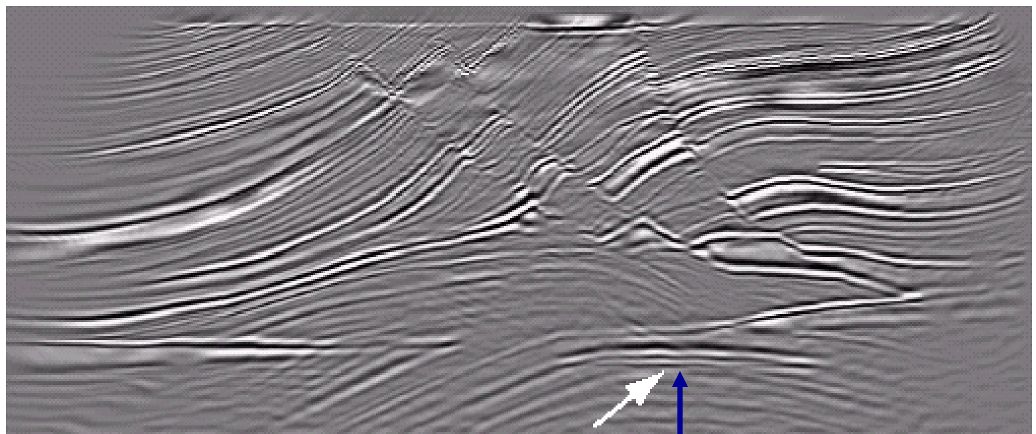
FIGURE 1.18 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

Each image gives a totally different view of the Pulsar.

OTHER IMAGING MODALITIES - ACOUSTIC IMAGING

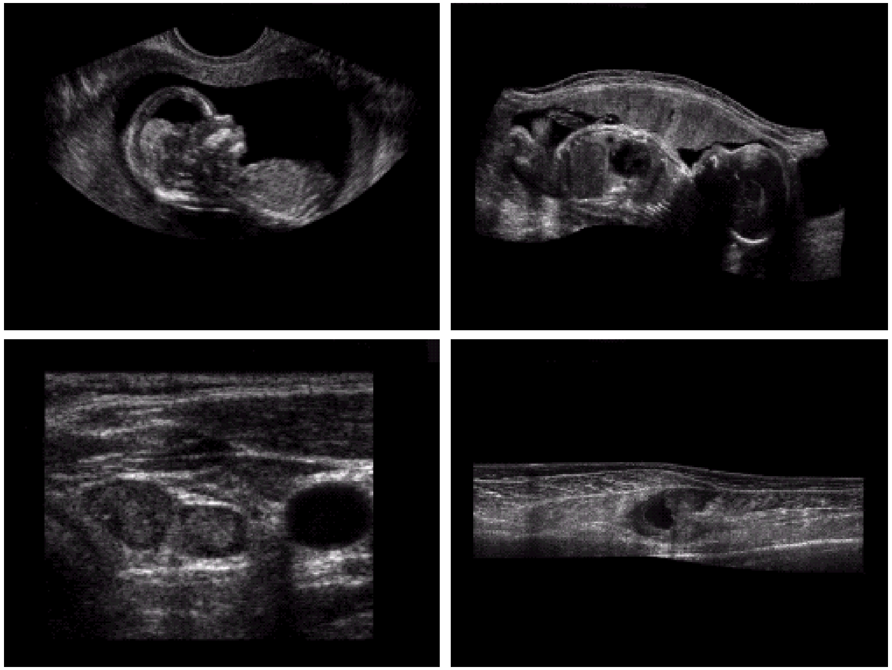
Major uses: geological exploration, industry, medicine

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.)



This target is brighter than the surrounding layers because the change in density in the target region is larger.

OTHER IMAGING MODALITIES - ULTRASOUND IMAGING

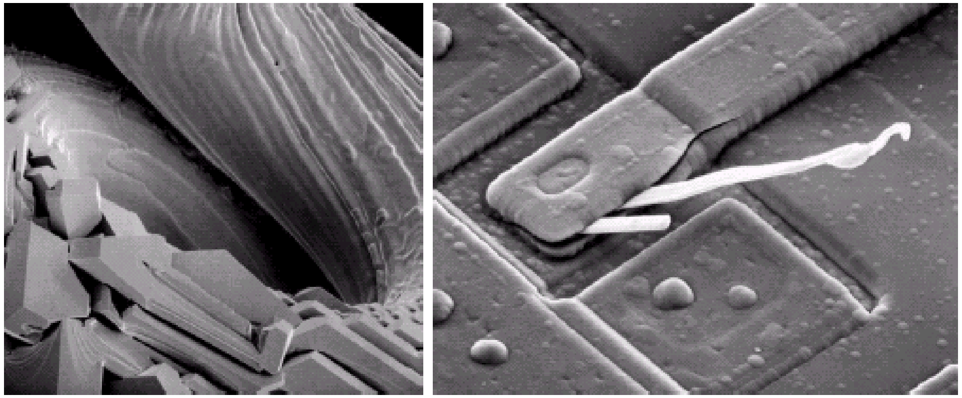


a b
c d

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.)

Ultrasound imaging: millions of HF sound pulses and echoes are sent and received each second.

OTHER IMAGING MODALITIES - ELECTRON MICROSCOPY



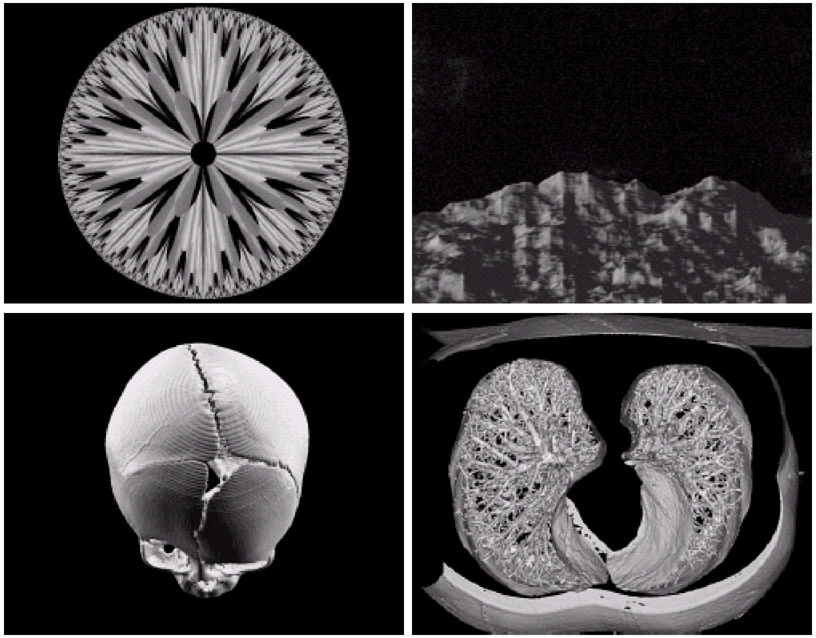
a b

FIGURE 1.21 (a) 250× SEM image of a tungsten filament following thermal failure. (b) 2500× SEM image of damaged integrated circuit. The white fibers are oxides resulting from thermal destruction. (Figure (a) courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene; (b) courtesy of Dr. J. M. Hudak, McMaster University, Hamilton, Ontario, Canada.)

Electron microscopes

- **use a focused beam of electrons instead of light.**
- **are capable of very high magnification (10,000X or more).**
- **transmission electron microscope (TEM), scanning electron microscope (SEM)**

OTHER IMAGING MODALITIES - COMPUTER-GENERATED OBJECTS



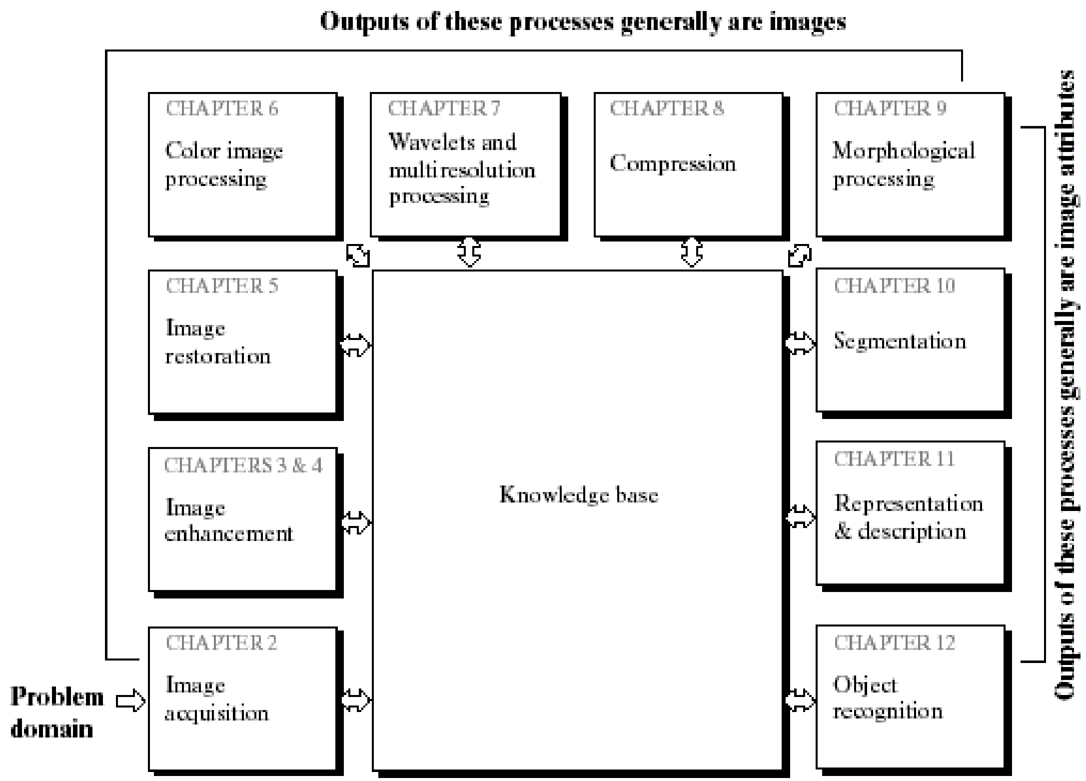
a b
c d

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.)

Images that are not obtained from physical objects.

FUNDAMENTAL STEPS IN DIGITAL IMAGE PROCESSING

FIGURE 1.23 Fundamental steps in digital image processing.



WHAT ARE THE FUNDAMENTAL STEPS?

- **Image acquisition**: capturing an image in digital form.
- **Image enhancement**: making an image look better in a subjective way.
- **Image restoration**: improving the appearance of an image objectively.
- **Color image processing**: color models and basic color processing
- **Wavelets and multiresolution processing: Wavelet transform in one and two dimensions.**
- **Image compression**: reducing the stored and transmitted image data.
- **Morphological image processing**: extracting image components that are useful in the representation and description of shape.
- **Image segmentation**: partitioning an image into its constituent parts or objects.
- **Representation and description**: boundary representation vs. region representation. Boundary descriptors vs. region descriptors.
- **Recognition**: assigning a label to an object based on its descriptors.

COMPONENTS OF AN IMAGE PROCESSING SYSTEM

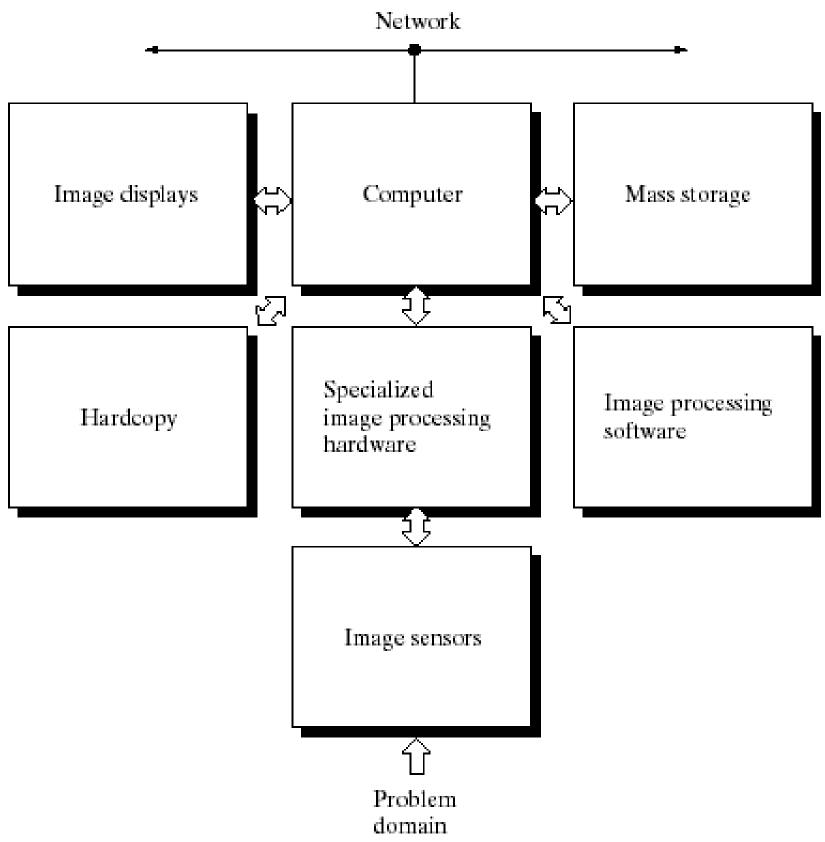


FIGURE 1.24 Components of a general-purpose image processing system.

WHAT ARE THE COMPONENTS?

- **Image sensors and specialized IP HW**
  - **A physical device that is sensitive to the energy radiated by the object.**
  - **A digitizer that converts the output of the physical sensing device into digital form.**
  - **HW that performs other primitive operations.**
- **Computer: Can range from a PC to a supercomputer.**
- **Image processing SW: Specialized modules that perform specific tasks.**
- **Mass storage**
  - **Short term storage: main memory, frame buffers**
  - **On-line storage: magnetic disks and optical disks**
  - **Archival storage: magnetic tapes and optical disks in "jukeboxes"**
- **Hard copy: all types of printers, film cameras, optical disks (CDs and DVDs).**
- **Networking: bandwidth is the key consideration.**