Unit 1. Introduction to Digital Image Processing

What is Digital Image Processing?

- An image can be defined as a two-dimensional function, $f(x,y)$
  - $x$ and $y$ are spatial (plane) coordinates
  - The function value $f$ at any pair of coordinates $(x,y)$ is called the **intensity**, or **gray scale** of the image
  - When $x$, $y$ and the values of $f$ are all finite, discrete quantities, we call the image a digital image
  - A digital image is composed of a finite number of elements called picture (image) elements, pels, and pixels

© 2002 R. C. Gonzalez & R. E. Woods
What is Digital Image Processing?

- DIP refers to processing digital images by means of a digital computer.
- The definition of image processing to be a discipline in which both input and output of a process are images is too limiting.
- Close relationship to computer vision (close to AI), which aims to emulate human vision.
- No clear-cut boundary from image processing to computer vision.

Three types of processes in the continuum from image processing to computer vision:

- **Low-level processes:** both input and output are images, such as noise reduction, contrast enhancement, image sharpening.
- **Mid-level processes:** input are images, but outputs are attributes extracted from those images, such as segmentation.
- **High-level processes:** understanding, recognition.
Origins of Digital Image Processing

Newspaper industry when pictures were sent by submarine cable in early 1920s

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

**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 1920 from London to New York by 15-tone equipment. (McFarlane.)
Origins of Digital Image Processing

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.)

Examples of Fields that Use Digital Image Processing

Digital image processing has impact in some way on almost every area.

![Energy of one photon (electron volts)](energy_of_one_photon.png)

Figure 1.5 The electromagnetic spectrum arranged according to energy per photon.
Gamma-Ray Imaging

PET (Positron Emission Tomography)

X-Ray Imaging
Ultraviolet Imaging

Applications:
Industrial inspection, microscopy, biological images, astronomical observation

Visible Band: Microscopy Images
Visible & Infrared Band: Remote Sensing

<table>
<thead>
<tr>
<th>Band No.</th>
<th>Name</th>
<th>Wavelength (μm)</th>
<th>Characteristics and Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Visible blue</td>
<td>0.45–0.52</td>
<td>Maximum water penetration</td>
</tr>
<tr>
<td>2</td>
<td>Visible green</td>
<td>0.52–0.60</td>
<td>Good for measuring plant vigor</td>
</tr>
<tr>
<td>3</td>
<td>Visible red</td>
<td>0.63–0.69</td>
<td>Vegetation discrimination</td>
</tr>
<tr>
<td>4</td>
<td>Near infrared</td>
<td>0.76–0.80</td>
<td>Biomass and shoreline mapping</td>
</tr>
<tr>
<td>5</td>
<td>Middle infrared</td>
<td>1.55–1.75</td>
<td>Moisture content of soil and vegetation</td>
</tr>
<tr>
<td>6</td>
<td>Thermal infrared</td>
<td>10.4–12.5</td>
<td>Soil moisture; thermal mapping</td>
</tr>
<tr>
<td>7</td>
<td>Middle infrared</td>
<td>2.06–2.35</td>
<td>Mineral mapping</td>
</tr>
</tbody>
</table>

TABLE 1.1
Thematic bands in NASA's LANDSAT satellite.

Remote Sensing: Multispectral Imaging

FIGURE 1.19 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)
Multispectral Image

FIGURE 3.11
Multispectral image of Hurricane Andrew taken by NOAA GEOS (Geostationary Environmental Operational Satellite) sensors. (Courtesy of NOAA.)

Infrared Imaging

FIGURE 3.32
Infrared images of North America. These images are provided for reference (courtesy of NOAA).
Infrared Imaging

FIGURE 2.13
Infrared satellite images of the remaining populated part of the world. The small grey map is provided for reference.
(Courtesy of NOAA.)

Visual Spectrum:
Automated Visual Inspection

FIGURE 3.14
Some examples of mechanical failures detected using digital image processing. (a) A railroad track. (b) Bolt. (c) Bond in semiconductor. (d) Cored. (e) Image of load cell. (f) (c) and (e) courtesy of All Pro Site, Percussion Corporation.)
Examples in Visual Spectrum

![Image 1.15](image1.png)

Imaging in Microwave Band: Radar

![Image 1.16](image2.png)
Imaging in Radio Band: MRI

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 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)
Acoustic Imaging: Seismic Imaging

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 Osher, Sandia National Laboratories.)

Hundreds of Hertz low-frequency sound

Ultrasound Imaging

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

Millions of Hertz high-frequency sound
Scanning Electron Microscope (SEM)

**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.)

Computer-Generated Fractal Images

**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.)
Why do we need image processing?

- Facilitate picture storage and transmission
  - Efficiently store an image in a digital camera
  - Send an image from Mars to Earth
- Prepare for display or printing
  - Adjust image size
  - Halftoning
- Enhance and restore images
  - Remove scratches from an old movie
  - Improve visibility of tumor in a radiograph
- Extract information from images
  - Read the ZIP code on a letter
  - Measure water pollution from aerial images

Fundamental Steps in DIP

Outputs of these processes are images:
- CHAPTER 5: Color image processing
- CHAPTER 6: Wavelets and multiresolution processing
- CHAPTER 8: Compression
- CHAPTER 9: Morphological processing
- CHAPTER 10: Segmentation
- CHAPTER 11: Representation & description
- CHAPTER 12: Object recognition

Problem domain
Knowledge base

Outputs of these processes are image attributes:

© 2002 R. C. Gonzalez & R. E. Woods
General-Purpose Image Processing System

![Diagram of a general-purpose image processing system.]

Image Restoration Example

**Restoration of image from Hubble Space Telescope**

![Images of Saturn: Observed image on the left and Restored image on the right.](image-url)
Color Image Restoration

Degraded image

Restored image

Source: TFL, Northeastern University, Chicago

Noise Filtering

Noisy image

Degraded image

Reconstructed Estimator - GMF

Noise-reduced image

© 2002 R. C. Gonzalez & R. E. Woods
Halftoning

Region Extraction (Segmentation)
Face Detection Examples

Face Detection

Face Tracking
Face Recognition/Retrieval

Face Morphing

OCR (Optical Character Recognition)