ELIC 629

Digital Image Processing

Fall 2005

Introduction

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Overview (1):

- **What is Digital Image Processing (DIP) ?**
  - What is an image ?
  - Relationship to computer vision
- **Origins of Digital Image Processing**
  - Brief historical overview
- **Fields that Use Digital Image Processing**
  - Image categorization and the electromagnetic spectrum (EM)
    - Gamma ray, x-ray, ultraviolet, visible, infrared, microwave, radio wave

Overview (2):

- **Fundamental Steps**
  - Methodologies
  - Overview of what this course will cover
- **Components of a Digital Image Processing System**
  - Hardware
  - Software
- **Conclusions**
  - Summary

What is Digital Image Processing ?

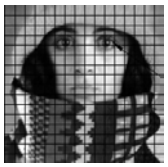
What is a Digital Image ? (1):

- **A Discrete Two-Dimensional Function f(x,y)**
  - x,y denote the spatial coordinates
    - Consider a table (or matrix or grid) where x indicates the row and y the column
    - Example: matrix with 5 rows and 6 columns (5 x 6)

Row (x) \ Column (y)	0	1	2	3	4	5
0	0,0	0,1	0,2	0,3	0,4	0,5
1	1,0	1,1	1,2	1,3	1,4	1,5
2	2,0	2,1	2,2	2,3	2,4	2,5
3	3,0	3,1	3,2	3,3	3,4	3,5
4	4,0	4,1	4,2	4,3	4,4	4,5

What is a Digital Image ? (2):

- **Intensity**
  - The value (or amplitude) of the function f at spatial coordinates (x,y)
    - Finite and discrete when considering digital images
    - Non-discrete and non-finite → not a digital image!



NOTE:

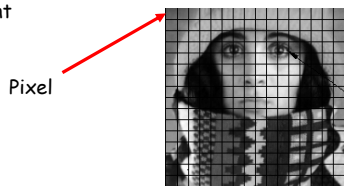
The digital image is obtained by sampling an analog 2D image but for now, lets not be concerned with this. Sampling will be discussed next week!

What is a Digital Image ? (3):

- **Intensity (continued…)**
  - The intensity of a digital image can vary from a wide range of values
    - Typical examples: 0 – 255, 0 – 32,767 etc…
  - Can also have more than one intensity value associated with each spatial location
    - Color images → one intensity value for each color (e.g., red, green, blue color channels – more of this in the future)…
    - Single color → intensity also known as gray level

What is a Digital Image ? (4):

- **Pixel**
  - Each element of a digital image e.g., each entry in the grid (matrix) with its distinct spatial location
  - Also known as
    - Picture element or pel
    - Image element



Digital Image Processing (1):

- **Definition**
  - Processing digital images with a digital computer
- **Two Principle Applications of Digital Image Processing**
  - Improvement of images for human interpretation
  - Processing of image data for storage, transmission and representation for autonomous machine perception

Digital Image Processing (2):

- **Covers a Large and Varied Field of Applications**
  - Although the human visual system can only respond to the visual band of the electromagnetic spectrum, machines can be used to image (sample) the (almost) entire electromagnetic spectrum
    - More about this later

Digital Image Processing (3):

- **Relationship to Other Fields**
  - Computer vision
    - Create real-world model from one or more images
    - Recovers useful information about a scene from a 2D projection of the 3D world
    - Ultimately emulate human visual system!
  - Where does image processing stop and image analysis/computer vision start ?
    - No clear cut boundaries!
    - How about defining image processing such that both input and output are images ?

Digital Image Processing (4):

- **Relationship to Other Fields (cont…)**
  - Too restrictive! e.g., then the common operation of computing the average intensity of an image is not part of image processing!
  - A useful paradigm is to consider three types of computerized processes
    - Low level → primitive operations such as noise reduction, contrast enhancement, image sharpening
    - Mid Level → segmentation, classification,
    - High level → making sense of recognized objects, even performing cognitive functions

Digital Image Processing (5):

- **Definition Used in this Course**
  - Processes whose inputs and outputs are images but we also include processes which extract attributes from images including the recognition of individual objects
- **As an "Aside" – Computer Graphics**
  - Computer used to recreate a "picture" given some description of a scene/environment
    - "Almost" like the opposite problem to image processing although there is some overlap!

Origins of Digital Image Processing (1):

- **One of the First Applications was in the Newspaper Industry**
  - Pictures sent by submarine cable between Europe and North America
    - Bartlane transmission system → transfer picture in a couple of hours instead of more than one week
    - Code picture at the transmitting end, send coded data over cable, receive and decode at the receiving end
    - Five discrete levels of gray and later up to 15

Origins of Digital Image processing (2):

- **Bartlane Transmitter**

The Bartlane Transmitter.

- **Sample Image**

Picture Transmitted and Reproduced by the Bartlane System.

Origins of Digital Image Processing (3):

- **Early Examples did not Include Computer!**
  - Technically, do not fall into our definition of image processing since we require the use of a computer!
    - Although the notion of a computer can be traced back more than 5000 years, the modern digital computer dates back to the 1940s and the two key concepts introduced by John von Neumann
      1. Memory to hold stored programs and data
      2. Conditional branching

Origins of Digital Image Processing (4):

- **Image Processing VERY Computationally Expensive!**
  - Early computers were very restrictive until the intro. of the transistor, high level programming languages, VLSI etc.
  - Not until the 1960s that the field of digital image processing, as we know it today was born!
  - Many motivations
    - Space/arms race of the cold war era
    - Medicine - medical imaging
    - Satellites etc.

Origins of Digital Image Processing (5):

- **From 1960s Until Presently, Digital Image Processing has Grown Vigorously!**
  - In addition, to space exploration and medicine, many more applications have arisen
    - Geographical
    - Industrial
    - Archeology
    - Satellite technology
    - Law enforcement
    - Biology, astronomy

Origins of Digital Image Processing (6):

- **Digital Image Processing no Longer Restricted to Professionals**
  - With the (affordable) computing power currently available and the internet, image processing has found its way into most peoples homes
    - PhotoShop™
    - Microsoft™ imaging utilities standard on Windows operating system
    - etc…
  - How many times have you modified an image on your PC ?

Fields that Use Digital Image Processing

Introduction (1):

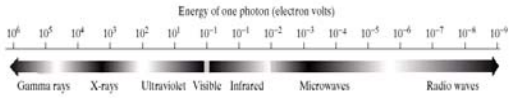
- **Digital Image Processing is All Around Us**
  - Every area of technical endeavor impacted by it
    - Immense breadth and importance
  - Given this large breadth, images are typically categorized according to their source
    - Principle (and most familiar) source for images today is the electromagnetic spectrum
    - This is not the only source → acoustic, ultrasonic, electronic

Electromagnetic Spectrum (1):

- **Electromagnetic Waves**
  - Conceptualized as:
    - Wave theory → propagating sinusoidal waves of varying wavelength or
    - Particle theory → stream of mass-less particles containing a certain amount of energy, moving at the speed of light (known as a photon)
    - There is also the dual theory in which both forms are present! We won't worry about this !!!

Electromagnetic Spectrum (2):

- **Grouping of Spectral Bands of EM Spectrum According to Energy per Photon we Obtain:**



  - Highest energy → gamma rays
  - Lowest energy → radio waves
  - No "smooth transition" between bands of the EM spectrum

Gamma Ray Imaging (1):

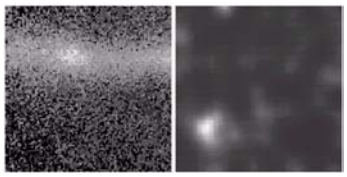
- **Primary Uses:**
  - Nuclear medicine (detect tumors etc.) – Idea:
    - Patient injected with radioactive isotope that emits gamma rays as it decays
    - Emission of gamma rays are collected by gamma ray detectors and image is constructed
  - Positron-Emission-Tomography (PET)
    - Patient given radioactive isotope that emits positrons as it decays
    - When positron meets electron, both destroyed and two gamma rays given off
    - Gamma rays are detected and using special detectors an image is constructed

Gamma Ray Imaging (2):

- **Nuclear Medicine Example:**
  - Complete bone scan

Gamma Ray Imaging (3):

- **Primary Uses (cont…)**
  - Astronomical observations
    - Many "objects" in space (e.g., stars ,galaxies etc.) naturally emit gamma ray radiation special sensors can detect and record this



Star in Cygnus constellation exploded 15,000 years ago and created a gas cloud which emits gamma radiation

X-Ray Imaging (1):

- **Oldest Sources of EM Radiation for Imaging**
  - Best known for medical diagnostics
    - Patient placed between "X-ray tube" and special film sensitive to X-ray radiation
    - Electrons are emitted from X-ray tube and go through patient
    - Intensity of X-rays is modified by absorption as they go through patient
    - Intensity collected at film and image is then created

X-Ray Imaging (2):

- **Other Applications of X-ray Imaging**
  - Angiography
    - Obtain images of blood vessels (angiograms)
    - X-ray contrast medium injected via catheter at appropriate location
    - X-ray image obtained and blood vessels highlighted

X-Ray Imaging (3):

- **Other Applications of X-ray Imaging (cont…)**
  - Computerized axial tomography (CAT scan)
    - The process of using computers to generate a three-dimensional image from flat (e.g., two-dimensional) X-ray pictures, one slice at a time…
    - CAT image is a "slice" taken perpendicularly through the patient
    - Patient is moved in the longitudinal direction
    - Has revolutionized medical medicine due to their high resolution and 3D capabilities

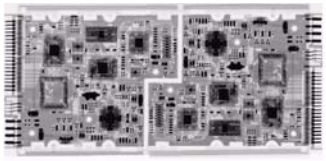
X-Ray Imaging (4):

Example CAT of Head

CAT Scan Apparatus

X-Ray Imaging (5):

- **Other Applications in Addition to Medicine**
  - Industrial processes
    - Imaging of parts/components to detect cracks and flaws



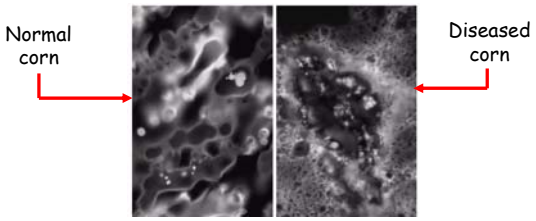
Commonly used to examine circuit boards to detect missing parts, cracks etc.

Ultraviolet Imaging (1):

- **Varied Applications**
  - Lithography
  - Industrial inspection
  - Microscopy → fluorescence microscopy one of the fastest growing fields of microscopy
  - Lasers
  - Biological imaging
  - Astronomical observation

Ultraviolet Imaging (2):

- **Example Ultraviolet Images**
  - Corn → detect diseased corn



Visible and Infrared Imaging (1):

- **Obviously the Most Widely Used Given our Sensitivity to the Visual Spectrum**
  - Low frequency (red) $\rightarrow$ 4.3×10^{14} Hz
  - High frequency (violet) $\rightarrow$ 7.5×10^{14} Hz
  - Often used in conjunction with infrared imaging
  - Various applications
    - Light microscopy
    - Law enforcement
    - Astronomy
    - Industrial applications
    - Remote sensing

Visible and Infrared Imaging (2):

- **Remote Sensing**
  - Definition:
    - The process of obtaining data or images from a distance, as from satellites or aircraft
  - Major area of visual/infrared imaging
  - Usually covers several bands of the visual/infrared spectrum
  - NASA's LANDSAT satellite
    - Primary purpose $\rightarrow$ Obtain and transmit images of earth from space for environmental monitoring purposes

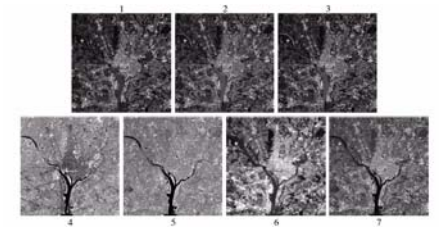
Visible and Infrared Imaging (3):

- **Thermatic Bands of LANDSAT**
  - Bands of interest

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

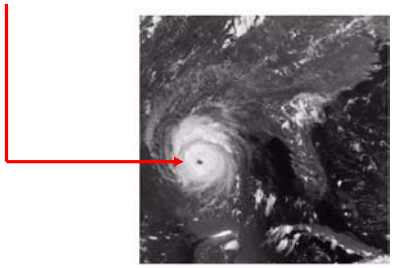
Visible and Infrared Imaging (4):

- **Example Images Obtained from LANDSAT**
  - Washington D.C. area
    - Detect vegetation, roads, rivers, buildings etc.



Visible and Infrared Imaging (5):

- **Further Examples of Visual Satellite Images**
  - Hurricane Andrew



Visible and Infrared Imaging (6):

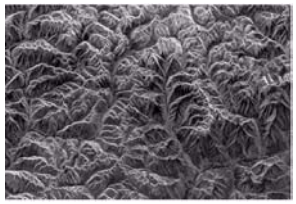
- **Infrared Image Example**
  - North America from Space

Microwave Imaging (1):

- **Dominant Use is Radar**
  - Ability to collect data over virtually any region, at any time, regardless of weather conditions or ambient light conditions
    - Penetrate clouds
    - At times, can see through vegetation, ice, sand…
  - Operates similar to flash camera
    - Provides its own illumination (microwave pulses) to illuminate area of interest and then "snaps" image
    - Instead of camera lens, antenna is used

Microwave Imaging (2):

- **Example Microwave Image**
  - Image of mountainous region of Tibet obtained from space satellite

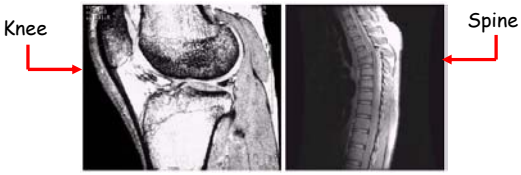


Radio Band Imaging (1):

- **Dominant Use is Medicine and Astronomy**
  - In medicine, popular technique is magnetic resonance imagine (MRI)
    - Patient placed in powerful magnet
    - Radio waves are passed through patient's body in short pulses
    - Each pulse causes another pulse to be emitted by the patients tissues
    - Location and strength of the pulses is determined by computer and 2D image is created based on this information

Radio Band Imaging (2):

- **Example MRI Image**
  - Human knee and spine → common uses of MRI
  - MRI images of any plane can be made



Other (Non-EM) Imaging Modalities (1):

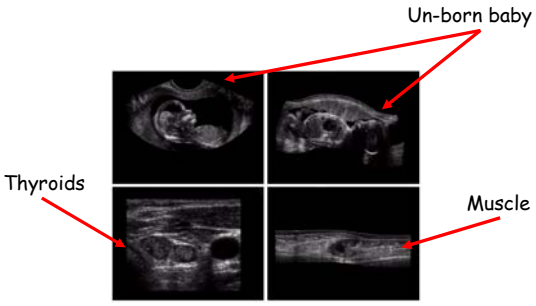
- **Acoustical Imaging**
  - Sound waves (typically low frequency, e.g., < 100Hz) are emitted from transmitter
  - Reflections of transmitted sound recorded by receiver
    - Image constructed based on time of arrival and intensity of echoes
  - Many applications
    - Geological exploration (oil and mineral exploration)
    - Industry
    - Medicine (ultrasound)

Other (Non-EM) Imaging Modalities (2):

- **Acoustical Imaging (cont…)**
  - Popular use of acoustical imaging is ultrasound
    - Viewing of unborn babies
    - Viewing other body tissues/bones
    - Can detect certain cancers
  - To construct typical ultrasound image, millions of pulses and echoes are emitted and received respectively each second
  - Pulses typically 1 – 5 MHz

Other (Non-EM) Imaging Modalities (3):

- Example Ultrasound Images



Fundamental Steps in Digital Image Processing

Two Broad Categories (1):

- Methods Whose Input and Output are Images
- Methods Whose Inputs are Images but Outputs are Attributes Extracted from these Images

Two Broad Categories (2):

- **Outline for Remainder of Course!**

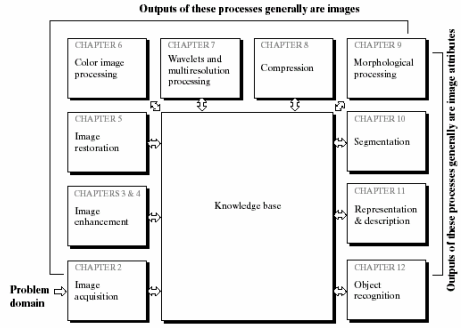


Image Enhancement (1):

- **Bring out Details that are Obscured or Highlight Certain Areas of an Image**
  - Simplest/most appealing areas of image processing
  - Subjective → highly dependent on the human observer
    - My idea of a "good" image may differ from yours!
  - Examples include adjusting image
    - Brightness
    - Contrast
    - Color etc…

Image Enhancement (2):

- **Example**
  - Removing "red-eye"

Before

After

Image Restoration (1):

- **Improving Image Appearance**
  - Real-life images typically contain noise which can arise from many aspects of the imaging process
    - Sensor itself
    - Environmental noise
    - Sampling
  - Objective
    - Typically based on mathematical or probabilistic models of image degradation

Image Restoration (2):

- **Example**
  - Old family photos
    - Cracks, wrinkles, tears, can disappear!
    - Faces can be made to look sharp and clear!

Before

After

Color Image Processing (1):

- **Most "Modern-day" Images are not Gray-Scale**
  - Consider the internet!
  - Typically three color channels
    - Red, green, blue (r,g,b)
    - Many times, each color is treated separately

Compression (1):

- **Techniques for Reducing Image Storage Requirements or bandwidth Required to Transmit Images**
  - Images can be very large in terms of memory especially when considering color images and potentially, image sequences over time
  - Storage capacity has increased tremendously over the last 10 years but transmission capacity has not been keeping up!

Morphological Processing (1):

- **Extraction of Image Components**
  - These components may be useful in the representation of and description of shape
- **Segmentation**
  - Partition an image into its constituent parts or objects
    - Background vs. foreground
    - Finding a specific object in an image
    - Typically not an easy task!

Description and Representation (1):

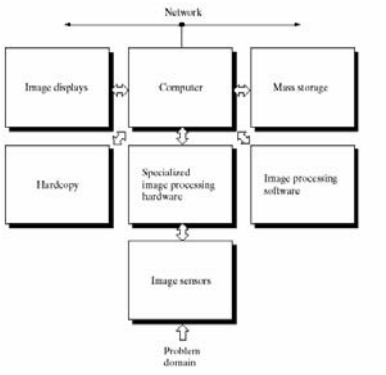
- **Extraction of Image Components**
  - Converting image data to a form suitable to computer processing
  - Typically follows the output of the segmentation stage which outputs ray pixel data representing either a boundary or a region
  - Decide whether data be represented as a boundary or a complete region
- **Recognition**
  - Assign labels to objects based on its descriptors

Knowledge Base (1):

- **Prior Knowledge**
  - Knowledge about a problem can be incorporated into a image processing modules via the knowledge base
  - Knowledge may include
    - Knowing regions in an image were an object may reside
  - Can reduce total processing e.g., no need to search the entire image!

Components of a Digital Image Processing System

Component Summary (1):



Component Summary (2):

- **Large Scale vs. Small Scale**
  - Until recently (e.g., late 1980s) image processing systems were fairly large and substantial
  - Recently, shifting towards single peripheral boards designed to be compatible with standard buses
    - Can be used with specialized equipment, workstations and even standard PCs
  - Recent trends also focus on image processing software and given the advances in computing power and storage
    - Many tasks can now be performed in software