Colorado School of Mines

Image and Multidimensional Signal Processing

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Digital Image Fundamentals
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Topics
• Image acquisition and formation
• Resolution and size of objects
• Spatial sampling and quantization
• Matlab exercises

Objectives
• Know how to estimate properties of image acquisition and formation, such as resolution and the size of objects that can be discerned
• Be familiar with the effects of spatial sampling and quantization on the quality of an image and its storage size
Notes:
Eyeball is about 20 mm in diameter
Retina contains both rods and cones
Fovea is about 1.5 mm in width, contains about 337,000 cones
Focal length about 17 mm
- Rods sensitive to low light (scotopic vision)
- Cones detect color, work in bright light (photopic vision)

**Figure 2.2**
Distribution of rods and cones in the retina.
Image Formation

**FIGURE 2.3**
Graphical representation of the eye looking at a palm tree. Point C is the optical center of the lens.

- Treat as pinhole camera – good approximation
  - Similar triangles

- What is the size of the tree on the retina?

- What if the tree were twice as far away?

\[
\frac{15}{100} = \frac{h}{17} \quad \text{or} \quad \frac{15}{100} = \frac{2h}{17}
\]

\[h = 2.55 \text{ mm}\]
Problem 2.1

• Assume the retina
  – Contains 337,000 sensor elements arranged in a square array, 1.5x1.5 mm
  – And the space between cones is equal to width of cone

• Estimate the diameter of the smallest printed dot that the eye can discern if the page on which the dot is printed is 0.2 m away from the eyes
  – Assume the visual system ceases to detect the dot when the image of the dot on the fovea becomes smaller than the diameter of one receptor (cone) in that area of the retina
Light and the Electromagnetic Spectrum

- Wavelength ($\lambda$) and frequency ($\nu$) are related by

$$\lambda = \frac{c}{\nu}$$

**FIGURE 2.11**
Graphical representation of one wavelength.

- To resolve an object, we must use a wavelength equal to the size of the object or smaller
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.
CCD (Charge coupled device)

- A 2D array of photosensitive transistors
- Charge accumulates during exposure
- Charges are transferred out to shift registers, read out sequentially
- Output is an analog signal (eg. RS-170, NTSC, PAL format)
- Can also be digitized and output in digital (via Firewire, USB, etc)

**Figure 2.2** A CCD (charge-coupled device) camera imaging a vase: discrete cells convert light energy into electrical charges, which are represented as small numbers when input to a computer.
Typical CCD cameras

- Example: Panasonic GP-MF130
- Sensor is 6x5 mm, 768x494 pixels
- Typical lens ~ 6mm focal length

Spectral Response

Field of view (see next slide)?
Field of View

- $f =$ focal length
- $\theta =$ field of view
- $h =$ image plane size

- $\tan(\theta/2) = (h/2) / f = (H/2) / D$

- Horizontal field of view:
  \[
  \tan(\theta/2) = (6\text{mm}/2) / (6\text{mm}) = 0.5
  \]
  \[
  \theta = 2 \arctan(0.5) = 53 \text{ degrees}
  \]

- $f$, $h$ can be in pixels or mm
- Horizontal, vertical fov could be different
Images can also be formed from

(a) A linear array of sensors that is swept
(b) A circular array, where the object is moved

**FIGURE 2.14** (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.
Example – Satellite Camera

- NOAA weather satellite
  - KLM series for polar (low Earth) orbits
Components
- Illumination $i(x,y)$
- Reflection $r(x,y)$

\[ f(x, y) = i(x, y) \cdot r(x, y) \]

$0 < i(x, y) < \infty$

$0 < r(x, y) < 1$

**FIGURE 2.15** An example of the digital image acquisition process. (a) Energy (“illumination”) source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.
Sampling and Quantization

- N bits per pixel allows $2^N$ values

**FIGURE 2.16** Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.
Examples

• An image has 8 bits per pixel
  – If unsigned, range of values is?
  – If signed (i.e., two’s complement), range is?
  – Number of bytes in a 3872 x 2592 pixel image?
FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.
Image Representation

- Image can be represented by an $xy$ plane
- Sampling partitions the plane into a grid of pixels, whose indices are integers
- We can also think of it as an $M \times N$ matrix of numbers
- We can index an element either by $(\text{row}, \text{col})$ or $(x, y)$

- We will use the convention
  - Top left pixel is $(1,1)$
  - $x$ index (or column) increases to the right
  - $y$ index (or row) increases down
Summary

• In digital cameras, the image is projected onto a 2D array of sensor elements.

• The image is (spatially) sampled by the sensor elements, and the intensities are quantized into discrete values.

• We can use the “pinhole” camera model to estimate the field of view and the size of objects projected onto the image.
Questions

• About how small an object can you see, using (a) visible light, (b) X-rays, or (c) microwaves?

• How does the human eye compare with a digital camera (e.g., in terms of resolution and sensitivity)?

• How could you measure the focal length of a camera? What units can it be expressed in?