Digital Image Processing

Lecture 2
(Image processing fundamentals)

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The best vision model we have!
Knowledge of how images form in the eye can help us with processing digital images
We will take just a whirlwind tour of the human visual system
Structure Of The Human Eye

The lens focuses light from objects onto the retina

The retina is covered with light receptors called cones (6-7 million) and rods (75-150 million)

Cones are concentrated around the fovea and are very sensitive to colour

Rods are more spread out and are sensitive to low levels of illumination

Blind-Spot Experiment

Draw an image similar to that below on a piece of paper (the dot and cross are about 6 inches apart)

\[
\text{●} \quad +
\]

Close your right eye and focus on the cross with your left eye

Hold the image about 20 inches away from your face and move it slowly towards you

The dot should disappear!
Muscles within the eye can be used to change the shape of the lens allowing us to focus on objects that are near or far away.

An image is focused onto the retina causing rods and cones to become excited which ultimately send signals to the brain.
Brightness Adaptation & Discrimination

The human visual system can perceive approximately $10^{10}$ different light intensity levels.

However, at any one time we can only discriminate between a much smaller number – *brightness adaptation*.

Similarly, the *perceived intensity* of a region is related to the light intensities of the regions surrounding it.
Brightness Adaptation & Discrimination (cont...)

Perceived brightness

Actual illumination
An example of *simultaneous contrast*
Brightness Adaptation & Discrimination (cont...)

For more great illusion examples take a look at: http://web.mit.edu/persci/gaz/
Light And The Electromagnetic Spectrum

Light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye.

The electromagnetic spectrum is split up according to the wavelengths of different forms of energy.
Reflected Light

The colours that we perceive are determined by the nature of the light reflected from an object.

For example, if white light is shone onto a green object most wavelengths are absorbed, while green light is reflected from the object.
Sampling, Quantization And Resolution

In the following slides we will consider what is involved in capturing a digital image of a real-world scene

– Image sensing and representation
– Sampling and quantization
– Resolution
Sampling
Sampling (aliasing)
Sampling

Continuous Tone Image → Sampler → Sampled Image → Quantizer → Sampled and Quantized Image
Image Sampling And Quantisation
Sampling

Digital Image Representation

$f(t) = \begin{bmatrix} 5 \\ 6 \\ 12 \\ 34 \\ 5 \\ 11 \end{bmatrix}$

$f(x,y) = \begin{bmatrix} 1 & 3 & 4 & 5 \\ 6 & 7 & 19 & 20 \\ 11 & 13 & 41 & 23 \\ 55 & 21 & 11 & 57 \end{bmatrix}$
A typical image formation system consists of an “illumination” source, and a sensor.

Energy from the illumination source is either reflected or absorbed by the object or scene, which is then detected by the sensor.

Depending on the type of radiation used, a photo-converter (e.g., a phosphor screen) is typically used to convert the energy into visible light.

Sensors that provide digital image as output, the incoming energy is transformed into a voltage waveform by a sensor material that is responsive to the particular energy radiation.

The voltage waveform is then digitized to obtain a discrete output.
FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.
Image Sensing and Acquisition
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.
Image Sensing and Acquisition

\[ 0 < i(x, y) < \infty \]

\[ 0 < r(x, y) < 1. \]

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

\[ 0 < f(x, y) < \infty. \]

\[ L_{\min} \leq l \leq L_{\max}. \]
- \( I = f(x,y) \)
- \( I \): intensity (or color)
- \((x,y)\): Position or Coordination
- When \((x,y)\) and \(I\) are finite and discrete quantities -
  \[\rightarrow \text{digital image}\]
- pixels, picture elements, image elements
Digital Image Representation

![Diagram of digital image representation with coordinates and pixel notation](image.png)
Effect of spatial resolution

**Figure 2.19** A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.
Effect of spatial resolution

FIGURE 2.25  Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.
Effect of spatial resolution

**FIGURE 2.20** (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.
Effect of graylevel quantization

Figure 2.21 (Continued)
(e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of
Dr. David R. Pickens,
Department of Radiology & Radiological Sciences,
Vanderbilt University Medical Center.)
Effect of spatial resolution

Images with different spatial resolutions:

- 512 x 512
- 256 x 256
- 128 x 128
- 64 x 64
- 32 x 32
- 16 x 16
Effect of graylevel quantization
Some Basic Relationships Between Pixels

Neighbors of a Pixel

\[ N_4 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix} \]

\( (x + 1, y), (x - 1, y), (x, y + 1), (x, y - 1) \).

\[ N_D = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \]

\( (x + 1, y + 1), (x + 1, y - 1), (x - 1, y + 1), (x - 1, y - 1) \).

\[ N_8 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \]
Some Basic Relationships Between Pixels

Connectivity

(a) 4-adjacency. Two pixels $p$ and $q$ with values from $V$ are 4-adjacent if $q$ is in the set $N_4(p)$.

(b) 8-adjacency. Two pixels $p$ and $q$ with values from $V$ are 8-adjacent if $q$ is in the set $N_8(p)$.

FIGURE 2.26 (a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) $m$-adjacency.
Some Basic Relationships Between Pixels

Distance

a. $D(p,q) \geq 0$  \hspace{0.5cm} D(p,q) = 0 \hspace{0.5cm} \text{iff} \hspace{0.5cm} p = q$

b. $D(p,q) = D(q,p)$

b. $D(p,q) \leq D(p,r) + D(r,q)$

Euclidean: $D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$

$D_4$ (City Block or Manhattan): $D_4(p,q) = |x-s| + |y-t|$

$D_8$ (Chessboard): $D_8(p,q) = Max\{|x-s|,|y-t|\}$
Rotation of Pixels

\[
R_\theta = \begin{bmatrix}
\cos \theta & \sin \theta & 0 & 0 \\
-\sin \theta & \cos \theta & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
R_\alpha = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \alpha & \sin \alpha & 0 \\
0 & -\sin \alpha & \cos \alpha & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
R_\beta = \begin{bmatrix}
\cos \beta & 0 & -\sin \beta & 0 \\
0 & 1 & 0 & 0 \\
\sin \beta & 0 & \cos \beta & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
v^* = R_\theta(S(Tv)) = A v
\]

\[
A = R_\theta S T
\]
Summary

We have looked at:

– Human visual system
– Light and the electromagnetic spectrum
– Image representation
– Image sensing and acquisition
– Sampling, quantisation and resolution

Next time we start to look at techniques for image enhancement