





Digital Image Processing

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Topic

- Digital Image Fundamentals
 - Visual Perception
 - Image Acquisition
 - Some basic knowledge















- photoreceptor cells (rods and cones) in the retina





Two types of light-sensitive receptors

Cones

cone-shaped less sensitive operate in high light color vision

Rods

rod-shaped highly sensitive operate at night gray-scale vision







Rod / Cone sensitivity







Distribution of Rods and Cones







• Why do we have two eyes?



Cyclope

Human





Two is better than one







Depth from Convergence







Mach Bands







Cornsweet illusion





















Penrose stairs





Going up or going down?





• Optical Illusions Our visual systems play lots of interesting tricks on us







What is an image?

- We can think of an **image** as a function, *f*, from R² to R:
 - f(x, y) gives the **intensity** at position (x, y)
 - Realistically, we expect the image only to be defined over a rectangle, with a finite range:

• $f: [a, b] \times [c, d] \rightarrow [0,1]$

• A color image is just three functions pasted together. We can write this as a "vector-valued" function:

$$f(x, y) = \begin{bmatrix} r(x, y) \\ g(x, y) \\ b(x, y) \end{bmatrix}$$

What is a digital image?

- We usually operate on **digital** (**discrete**) images:
 - Sample the 2D space on a regular grid
 - Quantize each sample (round to nearest integer)
- If our samples are Δ apart, we can write this as:
 f[*i*,*j*] = Quantize{*f*(*i* Δ, *j* Δ)}
- The image can now be represented as a matrix of integer values

62	79	23	119	120	105	4	0
10	10	9	62	12	78	34	0
10	58	197	46	46	0	0	48
176	135	5	188	191	68	0	49
2	1	1	29	26	37	0	77
0	89	144	147	187	102	62	208
255	252	0	166	123	62	0	31
166	63	127	17	1	0	99	30

What is a digital image?

Three types of images: Binary images $g(x,y) \in \{0, 1\}$ Gray-scale images $g(x,y) \in C$ typically $c = \{0, ..., 255\}$ Color Images three channels: $g_{\mathsf{R}}(x,y) \in C$ $g_{\mathsf{C}}(x,y) \in C$ $g_{\mathsf{R}}(x,y) \in C$

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What is a digital image?

Gray Scale Image

x	= 58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
y =															
41	210	209	204	202	197	247	143	71	64	80	84	54	54	57	58
42	206	196	203	197	195	210	207	56	63	58	53	53	61	62	51
43	201	207	192	201	198	213	156	69	65	57	55	52	53	60	50
44	216	206	211	193	202	207	208	57	69	60	55	77	49	62	61
45	221	206	211	194	196	197	220	56	63	60	55	46	97	58	106
46	209	214	224	199	194	193	204	173	64	60	59	51	62	56	48
47	204	212	213	208	191	190	191	214	60	62	66	76	51	49	55
48	214	215	215	207	208	180	172	188	69	72	55	49	56	52	56
49	209	205	214	205	204	196	187	196	86	62	66	87	57	60	48
			205	203	202	186	174	185	149	71	63	55	55	45	56
		- 0	211	199	217	194	183	177	209	90	62	64	52	93	52
		0	209	209	197	194	183	187	187	239	58	68	61	51	56
	100	1 3	203	209	195	203	188	185	183	221	75	61	58	60	60
			199	236	188	197	183	190	183	196	122	63	58	64	66
		V P	202	203	199	197	196	181	173	186	105	62	57	64	63

What is a digital image? Color Image

Image Acquisition

Digital Camera

The Eye

Pinhole camera model

• Pinhole model:

- Captures **pencil of rays** all rays through a single point
- The point is called Center of Projection (COP)
- The image is formed on the **Image Plane**
- Effective focal length *f* is distance from COP to Image Plane

Incoming energy lands on a sensor material responsive to that type of energy and this generates a voltage. Collections of sensors are arranged to capture images

Imaging Sensor

Line of Image Sensors

Array of Image Sensors

FIGURE 2.13

Combining a single sensor with motion to generate a 2-D image.

Image Formation

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

Sampling and Quantization Remember that a digital image is always only an **approximation** of a real world scene

FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

Sampling and Quantization

Sampling and Quantization

• Radiance:

The total amount of energy that flows from the light source, measured in watts(W).

• Luminance:

A measure of the amount of energy an observer perceives from a light source.

Luminance

Brightness

A subjective descriptor of light perception, impossible to measure.

Spatial Resolution
 A measure of the smallest discernible detail in an image.
 pixels per unit distance

Spatial Resolution

Spatial Resolution

a b c d

FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

Intensity Resolution

The smallest discernible change in intensity level.

Common: 8bits

Intensity Resolution

Intensity Resolution

e f g h

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 Radiological Sciences, Vanderbilt University Medical Center.)

- Connectivity
 - a) 4-adjacency
 - b) 8-adjacency
 - c) m-adjacency

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VIDEO A

abc def

FIGURE 2.25 (a) An arrangement of pixels. (b) Pixels that are 8-adjacent (adjacency is shown by dashed lines; note the ambiguity). (c) *m*-adjacency. (d) Two regions that are adjacent if 8-adjacency is used. (e) The circled point is part of the boundary of the 1-valued pixels only if 8-adjacency between the region and background is used. (f) The inner boundary of the 1-valued region does not form a closed path, but its outer boundary does.

Image Quality Assessment

- Objective Image assessment
 - PSNR (Peak Signal Noise Ratio)

$$PSNR = 10 \cdot \log_{10} \frac{255^2}{\frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \left[f(m,n) - g(m,n) \right]^2}$$

MSE (Mean Square Error)

$$MSE = \frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} [f(m,n) - g(m,n)]^2$$

Image Quality Assessment

- Subjective Image Assessment
 - MOS (Mean Opinion Score)
 - Grades

5	4	3	2	1	
Excellent	Good	Medium	Not Good	Bad	A

- DMOS (Difference Mean Opinion Score)
 - base on MOS
 - range from 1 100
- VQEG (Video Quality Experts Group)

Thank You!