Image Processing

Lecture 8

Introducing Image Processing

Revision

- 1. Introduction

  1.1 What Is Digital Image Processing?

  1.2 The Origins of Digital Image Processing

  1.3 Examples of Fields that Use Digital Image Processing

    1.3.1 Gamma-Ray Imaging

    1.3.2 X-ray Imaging

Revision

- *2. Digital Image Fundamentals*

  2.1 Elements of Visual Perception

  2.1.1 Structure of the Human Eye

  2.2 Light and the Electromagnetic Spectrum

  2.3 Image Sensing and Acquisition

  2.3.1 Image Acquisition Using a Single Sensor

  2.3.2 Image Acquisition Using Sensor Strips

  2.3.3 Image Acquisition Using Sensor Arrays

  2.3.4 A Simple Image Formation Model

  2.4 Image Sampling and Quantization

  2.4.1 Basic Concepts in Sampling and Quantization

  2.4.2 Representing Digital Images

  2.4.3 Spatial and Gray-Level Resolution

  2.4.5 Zooming and Shrinking Digital Images

2.5 Some Basic Relationships Between Pixels

2.5.1 Neighbors of a Pixel

2.5.2 Adjacency, Connectivity, Regions, and Boundaries

2.5.3 Distance Measures

2.5.4 Image Operations on a Pixel Basis

A Simple Image Formation Model

The values given in Eqs. (2.3-3) and (2.3-4) are theoretical bounds. The following *average* numerical figures illustrate some typical ranges of $i(x, y)$ for visible light. On a clear day, the sun may produce in excess of 90,000 lm/m^2 of illumination on the surface of the Earth. This figure decreases to less than 10,000 lm/m^2 on a cloudy day. On a clear evening, a full moon yields about 0.1 lm/m^2 of illumination. The typical illumination level in a commercial office is about 1000 lm/m^2. Similarly, the following are some typical values of $r(x, y)$: 0.01 for black velvet, 0.65 for stainless steel, 0.80 for flat-white wall paint, 0.90 for silver-plated metal, and 0.93 for snow.

Revision

- **3. Image Enhancement in the Spatial Domain**

  3.2 Some Basic Gray Level Transformations

  3.2.1 Image Negatives

  3.2.2 Log Transformations

  3.2.3 Power-Law Transformations

  3.2.4 Piecewise-Linear Transformation Functions

  3.3 Histogram Processing

  3.3.1 Histogram Equalization

  3.3.3 Local Enhancement 103

  3.4 Enhancement Using Arithmetic/Logic Operations

  3.4.1 Image Subtraction

  3.4.2 Image Averaging

Revision

3.5 Basics of Spatial Filtering

3.6 Smoothing Spatial Filters

3.6.1 Smoothing Linear Filters

3.6.2 Order-Statistics Filters

3.7 Sharpening Spatial Filters

3.7.1 Foundation

3.7.2 Use of Second Derivatives for Enhancement– The Laplacian

3.7.3 Use of First Derivatives for Enhancement- The Gradient

Revision

- **4. Image Enhancement in the Frequency Domain**
  - **4.2 Fourier Transform**
    - 4.2.1 The One-Dimensional Fourier Transform and its Inverse
    - 4.2.2 The Two-Dimensional DFT and Its Inverse 154
    - 4.2.3 Filtering in the Frequency Domain 156
    - 4.2.4 Correspondence between Filtering in the Spatial and Frequency Domains
  - **4.3 Smoothing Frequency-Domain Filters 167**
    - 4.3.1 Ideal Lowpass Filters 167
    - 4.3.2 Butterworth Lowpass Filters 173
    - 4.3.3 Gaussian Lowpass Filters 175

Revision

4.4 Sharpening Frequency Domain Filters 180

4.4.1 Ideal Highpass Filters 182

4.4.2 Butterworth Highpass Filters 183

4.4.3 Gaussian Highpass Filters 184

Other Topics

5. *Image Restoration*
6. *Color Image Processing* (*RGB*, CMY, CMYK, HSI Color Models)
7. *Wavelets and Multiresolution Processing*
8. *Image Compression*
9. *Morphological Image Processing*
10. *Image Segmentation*
11. *Representation and Description*
12. *Object Recognition*

Image Compression

Image Compression

- Data Compression aims to reduce the volume of information to be stored into storage device or to reduce the communication bandwidth required for its transmission over the networks

- Image Compression is the task of reducing the amount of data required to represent a digital image.

Image Compression

- The task of compression technique consists of two components, an encoding algorithm that takes the information and generates a compressed representation, and a decoding algorithm that reconstructs the original information or some approximation of it.

Image Compression

- Compression techniques can be classified into two main categories lossless compression techniques and lossy compression techniques
- Lossless Compression such as :

 1. Run Length encoding.

 2. Differential encoding.

 3. Huffman encoding.

- Lossy Compression such as : *Transform encoding*

Run Length

- Probably the simplest coding scheme.
- The basic idea of RLE is when the source information comprises long substrings or binary digit of the same character or binary digit
- The source is compressed in the form of a different set of codewrods which indicate particular character or bit and an indication of the number of characters or bits in the substrings.
- For example, the string: acccbbaaabb could be represnted as: (a, 1), (c, 3), (b, 2), (a, 3), (b, 2).

Differential encoding

- Differential encoding is used where the values are large and the differences between successive values are relatively small.
- The source information are compressed through representing it by codewords which indicates only the difference in amplitude between the current value being encoded and the immediately preceding value.
- For example, the source string: 16 17 15 16 13 15 17, could be represented as: 16 1 –2 1 –3 –2 1

Variable Length Coding

- Huffman coding : By using Huffman coding the symbols are naturally assigned codes that reflect the frequency distribution.

- Highly frequent symbols will be given short codes, and infrequent symbols will have long codes. This code is known as variable length code (VLC).

Huffman Coding

Original source		Source reduction			
Symbol	Probability	1	2	3	4
a_2	0.4	0.4	0.4	0.4	0.6
a_6	0.3	0.3	0.3	0.3	0.4
a_1	0.1	0.1	0.2	0.3	
a_4	0.1	0.1	0.1		
a_3	0.06	0.1			
a_5	0.04				

- From Information theory
- Average information per source output (entropy) :

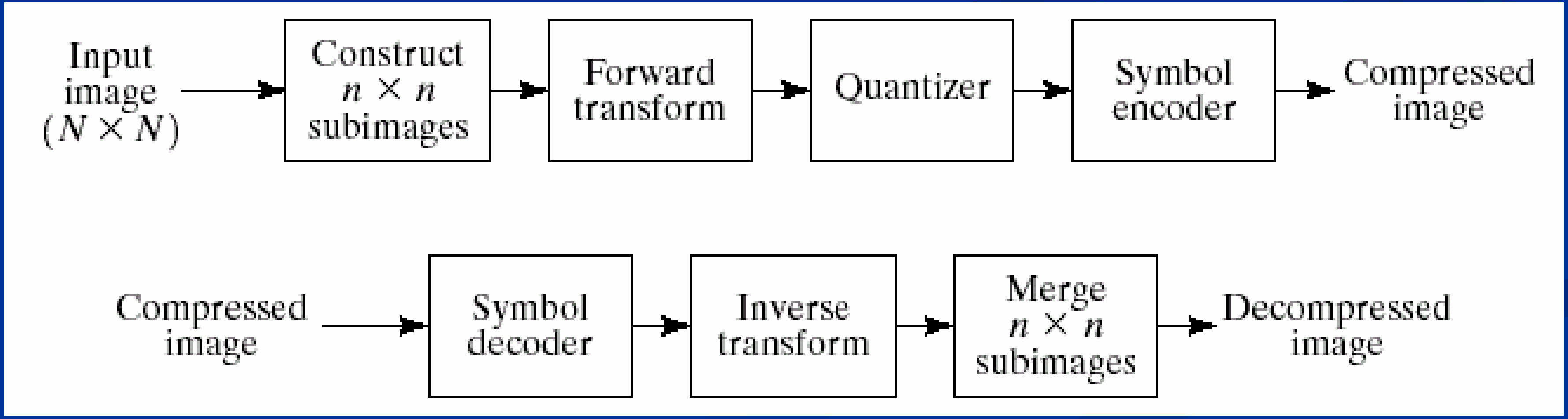
$$H(\mathbf{z}) = -\sum_{j=1}^{J} P(a_j)\log P(a_j)$$

- The average number of bits to represent each pixel (Average of bits):

$$L_{avg} = \sum_{k=0}^{L-1} l(r_k)\,p_r(r_k)$$

Transform Coding

- The idea of transform encoding is to transform the source information from one form into another which lending itself more readily to the application of compression.



Transform Coding

- The transformation of 2D matrix of the original image can be carried out using a mathematical technique known as discrete cosine transform (DCT) applying after dividing images into sub-blocks.

$$T_{ij} = \frac{1}{\sqrt{2N}} C_u C_v \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f_{xy} \cos\left[\frac{(2x+1)u\pi}{2N}\right] \cos\left[\frac{(2y+1)v\pi}{2N}\right]$$

$$\text{where } C_u \text{ and } C_v = \begin{cases} 1/\sqrt{2} & \text{for } \mathrm{i}, \mathrm{j} = 0 \\ 1 & \text{for all other values of } \mathrm{i} \text{ and } \mathrm{j} \end{cases}$$

- The produced Blocks Contains DC and AC coefficients.

Transform Coding

- Bit-allocation done using special mask such as Zonal mask.

1	1	1	1	1	0	0	0
1	1	1	1	0	0	0	0
1	1	1	0	0	0	0	0
1	1	0	0	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

8	7	6	4	3	2	1	0
7	6	5	4	3	2	1	0
6	5	4	3	3	1	1	0
4	4	3	3	2	1	0	0
3	3	3	2	1	1	0	0
2	2	1	1	1	0	0	0
1	1	1	0	0	0	0	0
0	0	0	0	0	0	0	0

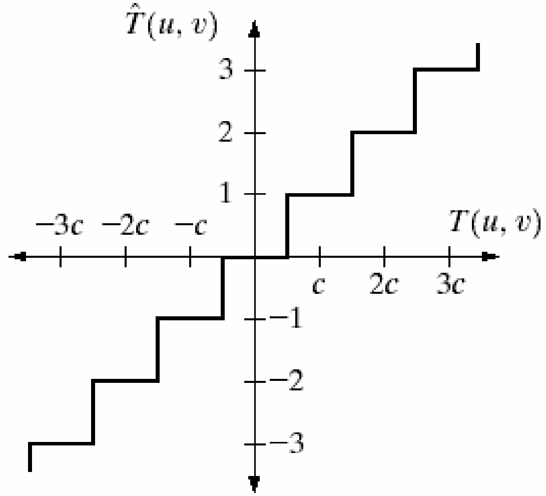
1	1	0	1	1	0	0	0
1	1	1	1	0	0	0	0
1	1	0	0	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

0	1	5	6	14	15	27	28
2	4	7	13	16	26	29	42
3	8	12	17	25	30	41	43
9	11	18	24	31	40	44	53
10	19	23	32	39	45	52	54
20	22	33	38	46	51	55	60
21	34	37	47	50	56	59	61
35	36	48	49	57	58	62	63

- Q : what is the type of this phase ?

Transform Coding

- Quantization using special matrix such as :



16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

Transform Coding (JPEG)

- DC and AC coding, DC using Difference encoding and AC using VLC.
- Scanning AC coefficients using an appropriate principle such as zeg-zag scan.
- EOB used in the end of encoded blocks.

quantized

-26	-3	-6	2	2	0	0	0
1	-2	-4	0	0	0	0	0
-3	1	5	-1	-1	0	0	0
-4	1	2	-1	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

1-D Zigzag scanning : [-26 –3 1 –3 –2 –6 2 –4 1 –4 1 1 5 0 2 0 0 –1 2 0 0 0 0 0 –1 –1 EOB]

Symbols to be coded : (DPCM =-9, assumed),(0,-3),(0,1),(0,-3),(0,-2),(0,-6),(0,2),(0,-4),(0,1),(0,-4),(0,1),(0,1),(0,5),(1,2),(2,-1),(0,2),(5,-1),(0,-1),EOB

Final codes :
1010110,0100,001,0100,0101,100001,0110,100011,001,100011,001,001,100101,1110011
0,110110,0110,11110100,000,1010

1D
Discrete Fourier Transform (DFT)

- Suppose $\{f(0), f(1), \ldots, f(M-1)\}$ is a sequence/vector/1-D image of length M. Its M-point DFT is defined as

$$F(u) = \sum_{x=0}^{M-1} f(x) e^{-j\frac{2\pi}{M}ux}, u = 0,1,2,\ldots\ldots, M-1$$

- Inverse DFT

$$f(x) = \frac{1}{M}\sum_{u=0}^{M-1} F(u) e^{j\frac{2\pi}{M}ux}, x = 0,1,2,\ldots\ldots, M-1$$

- Recall: $e^{j\theta} = \cos\theta + j\sin\theta$

Fourier Spectrum

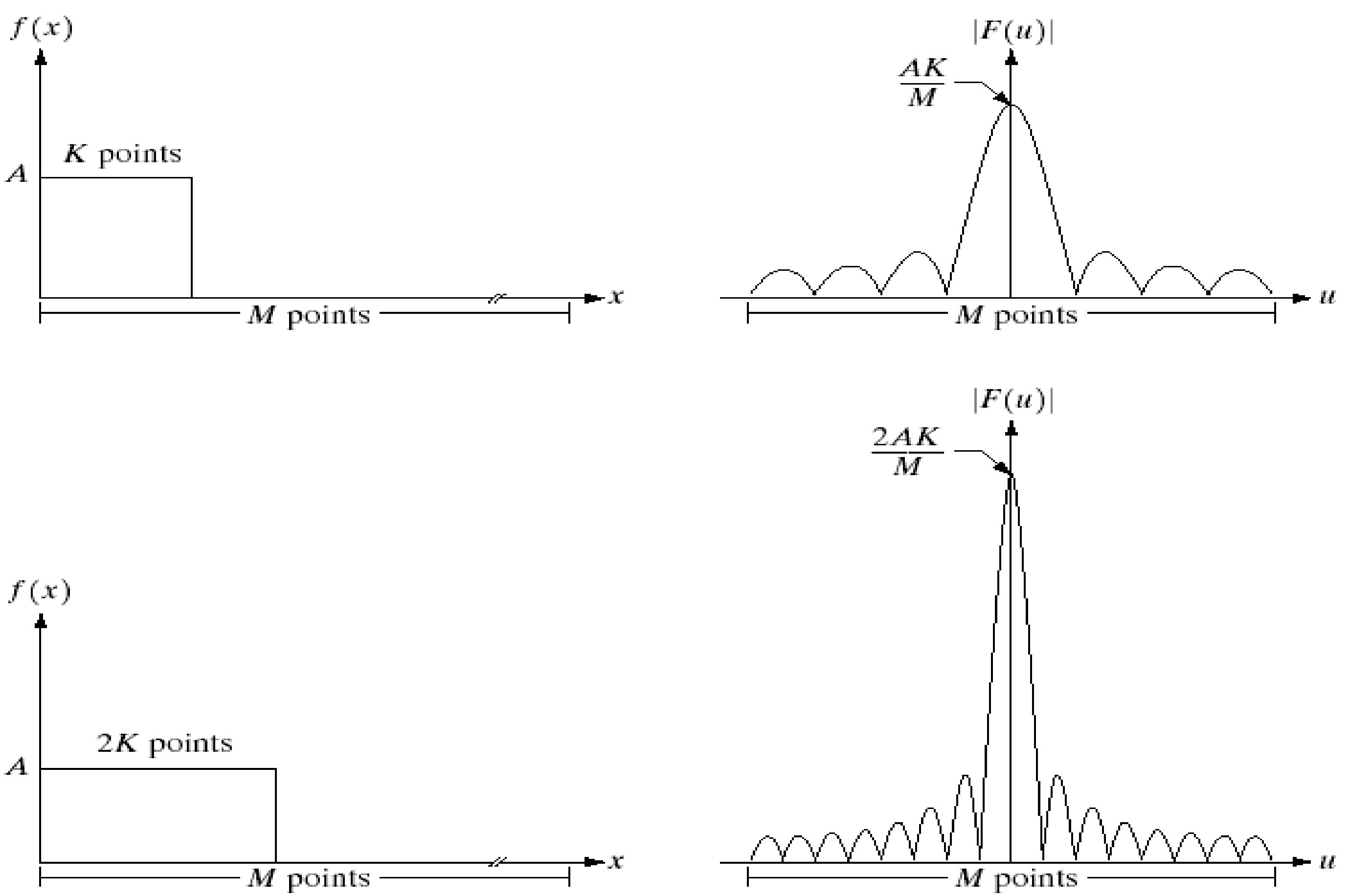


FIGURE 4.2 (a) A discrete function of M points, and (b) its Fourier spectrum. (c) A discrete function with twice the number of nonzero points, and (d) its Fourier spectrum.

Magnitude, Phase and Power Spectrum

$$F(u) = R(u) + jI(u)$$

Magnitude: $$|F(u)| = \sqrt{R^2(u) + I^2(u)}$$

Phase: $$\phi(u) = \tan^{-1}\left(\frac{I(u)}{R(u)}\right)$$

Power Spectrum: $$P(u) = |F(u)|^2$$

2D DFT

DFT

$$F(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)}$$

$$u = 0,1,2,\ldots,M-1, \quad v = 0,1,2,\ldots,N-1$$

IDFT

$$f(x,y) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u,v) e^{j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)}$$

$$x = 0,1,2,\ldots,M-1, \quad y = 0,1,2,\ldots,N-1$$

Magnitude, Phase and Power Spectrum

$$F(u,v) = R(u,v) + jI(u,v)$$

Magnitude: $$|F(u,v)| = \sqrt{R^2(u,v) + I^2(u,v)}$$

Phase: $$\phi(u,v) = \tan^{-1}\left(\frac{I(u,v)}{R(u,v)}\right)$$

Power Spectrum: $$P(u,v) = |F(u,v)|^2$$