DIGITAL IMAGE PROCESSING

Image Representation, Pixel Resolution, Sampling & Quantization

1. Image Representation & Pixel Resolution

1.1 Image Representation

Definition:

An image is represented as a two-dimensional function f(x, y), where:

- x → horizontal coordinate
- y → vertical coordinate
- f(x, y) → intensity (brightness) at point (x, y)

When x, y and intensity are finite and discrete, the image is called a Digital Image.

Digital Image Matrix (Example)

y \ x	0	1	2	3
0	120	130	140	150
1	110	125	145	160
2	100	115	135	155
3	90	105	120	140

- Each number is called a Pixel.
- Pixel = Picture Element

Pixel

- Smallest element of a digital image.
- Stores intensity or colour information.
- Every image consists of millions of pixels.

1.2 Pixel Resolution

Definition:

Pixel resolution refers to the number of pixels used to represent an image.

Higher resolution → More pixels → Better image quality
Lower resolution → Fewer pixels → Poor image quality

Example:

Low resolution images show blocky, coarse squares, while high resolution images show smooth, finely detailed grids. More pixels produce smoother edges and greater detail.

Common Image Resolutions

Resolution	Pixels
256 × 256	65,536
512 × 512	262,144
1024 × 1024	1,048,576

Resolution Formula

Total Pixels = Width × Height

Example: 640 × 480 = 640 × 480 = 307,200 pixels

Advantages of High Resolution

✓ Better clarity
✓ More details
✓ Suitable for medical and satellite images
✓ Better image processing results

Disadvantages of High Resolution

✗ Larger storage requirement
✗ More processing time
✗ Higher computational cost

Key Points (Exam Tips)

- Image = Matrix of Pixels
- Pixel = Smallest picture element
- Resolution = Number of pixels in an image
- Higher resolution → Better quality
- Lower resolution → Less detail

Memory Trick: More Pixels → Higher Resolution → Better Quality → More Memory

2. Sampling

2.1 Definition

Sampling is the process of converting a continuous image function f(x, y) into a discrete image by measuring its intensity values at discrete intervals.

It is the first step in converting an analog image into a digital image.

2.2 Why Sampling is Needed?

- Computer can work only with discrete data.
- Sampling converts a continuous image into a matrix of pixels.

2.3 Process of Sampling

Continuous image f(x, y) → Sampling (at intervals Δx, Δy) → Discrete image f[m, n]

m, n → integer coordinates
Δx, Δy → sampling intervals (spacing between samples)

2.4 Illustration

A continuous image f(x, y) is a smooth curve/surface over x and y. Sampling it at a grid of points (mΔx, nΔy) produces the sampled image f[m, n], shown as discrete dots on the grid.

At each grid point (mΔx, nΔy), the intensity is measured. These values form the pixels.

2.5 Sampling Intervals

- Δx → distance between two samples along the x-axis.
- Δy → distance between two samples along the y-axis.

If Δx and Δy are small → More samples → Better representation
If Δx and Δy are large → Fewer samples → Less detail (loss of information)

2.6 Effect of Sampling Interval

- Small sampling interval → High sampling density → Good quality
- Large sampling interval → Low sampling density → Poor quality (loss of details)

2.7 Key Points

✓ Sampling converts continuous image f(x,y) into discrete image f[m,n].
✓ It is done by measuring intensity at regular intervals.
✓ Output of sampling is a matrix of pixels.
✓ Choice of sampling interval decides the quality and amount of information.

Remember! More samples → More detail → Better quality

3. Quantization

3.1 Definition

Quantization is the process of mapping a large (continuous) set of intensity values to a small (discrete) set of levels. It reduces the number of possible intensity values.

Sampling → in space
Quantization → in intensity

3.2 Why Quantization is Needed?

- Computer can represent only a finite number of intensity levels.
- To reduce the amount of memory required.
- To simplify processing.

3.3 Process of Quantization

Continuous intensity values (0 to L−1) → Quantization (map to discrete levels) → Quantized image [k levels]

L – total no. of gray levels in the input image.
k – no. of gray levels after quantization (k < L).

3.4 Uniform Quantization

- The range [0, L−1] is divided into k intervals.
- Each interval is assigned a quantization level.
- Step size (Δ) = L / k

Example: If L = 256 and k = 8, Δ = 256/8 = 32
Quantization levels: 0, 32, 64, 96, 128, 160, 192, 224

3.5 Example

(a) Original image (L = 16 levels: 0 to 15)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

(b) Quantized image (k = 4 levels: 0 to 3)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3

- Step size Δ = L/k = 16/4 = 4
- Intervals: [0–3], [4–7], [8–11], [12–15]

- Representative levels: 0, 1, 2, 3

3.6 Effect of Quantization

- Fewer levels (small k) → More quantization error (posterization) → Poor quality
- More levels (large k) → Less quantization error → Better quality, more memory

3.7 Key Points

✓ Quantization reduces the number of intensity levels.
✓ It is a mapping from L levels to k levels ($k < L$).
✓ Uniform quantization uses equal interval size ($\Delta = L/k$).
✓ Choice of k controls quality and storage.