Lecture 1 - Introduction

Digital Image Processing

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Lecture 1 - Introduction

This lecture will cover:

- What is a digital image?
- What is digital image processing?
- Examples of digital image processing
- Steps of digital image processing
- Methods of digital image processing

Goal

Why do we need image processing

- Improvement of pictorial information for human interpretation
- Processing of image data for autonomous machine perception
  - Storage
  - Transmission
  - Representation
  - Description
  - Recognition
  - …… Many more.

Image processing is ubiquitous!

Stage of DIP

Low level process	Mid level process	High level process
INPUT: Image **OUTPUT:** Image **EXAMPLE:** Denoise Contrast enhancement Image sharpening	**INPUT:** Image **OUTPUT:** Attributes **EXAMPLE:** Segmentation Description Recognition	**INPUT:** Attributes **OUTPUT:** Understanding **EXAMPLE:** Image analysis Image understanding

There are no clear-cut boundaries
from image processing to computer vision

Fundamental Steps in DIP

- Image acquisition
- Image enhancement
- Image restoration
- Image reconstruction
- Image compression
- Image segmentation
- Image representation and description
- Object recognition

Applied methods in DIP

- **Spatial domain**
  - Pixel processing – grey processing
  - Neighborhood processing – gradient algorithm, Laplacian operator, smoothing operator, convolution algorithm
- **Frequency domain**
  - Discrete Fourier Transform (DFT)
  - Discrete Cosine Transform (DCT)
  - Discrete Wavelet Transform (DWT)
  - Walsh-Hadamard Transform (WHT)

Tools: Orthogonal transformation, Filtering, Convolution, Statistics etc.

Lecture 2 - Image Fundamentals

This lecture will cover:

- Image acquisition （图像获取）
- Sampling and Quantization （取样和量化）
- Pixels （像素）
- Image operation （图像的基本操作）
- Color space （彩色基础）

Image Operations

- Array and Matrix Operation （阵列与矩阵操作）
- Vector and Matrix Operation （向量矩阵操作）
- Linear and Nonlinear Operation （线性非线性操作）
- Set and Logical Operation （集合和逻辑操作）
- Arithmetic Operation （算数运算）
- Spatial Operation （空间运算）
- Image Transformation （图像变换操作）
- Probabilistic Methods （概率方法）

Lecture 3 – Spatial Filtering（空间滤波）

This lecture will cover:

- Spatial domain（空间域）
- Intensity Transformation （灰度变换）
- Histogram（直方图）
- Spatial Filtering（空间滤波器）
  - ✓ Smoothing（平滑）
  - ✓ Sharpening（锐化）

Intensity Transformation

- **Simplest image processing techniques**

$$s = T(r)$$

- **Types of Intensity Transformation**
  - Image Negatives（图像反转）
  - Log Transformation（对数变换）
  - Power-law (gamma) Transformation（幂律/伽马变换）
  - Piecewise-Linear Transformation（分段线性变换）

Histogram Processing

- Histogram Equalization （直方图均衡）
- Histogram Matching (Specification)（直方图匹配/规定化）
- Local Histogram Processing（局部处理）
- Histogram Statistics for Image Enhancement （直方图统计）

Spatial Filtering

A Spatial filter

- **is directly applied on the image**
- **is also called spatial masks（掩模）、kernels（核）、templates（模板）、windows（窗口）**
- **consists of**

  1) neighborhood 2) a predefined operation

- **can be linear and nonlinear**
  - Linear spatial filter corresponds to spectral filter in frequency domain
  - Nonlinear spatial filter cannot be accomplished in frequency domain

Smooth Filters (平滑滤波器)

- **Blurring – for preprocessing tasks**
- **Noise deduction**
  - **Linear filter : average filtering – lowpass filter in frequency domain**
  - **Nonlinear filter**

Sharpening Filter （锐化滤波器）

- **Spatial differentiation（空间微分）**
- **Sharpening filter**
  - **Laplacian filtering（拉普拉斯算子）**
  - **Unsharp Masking（非锐化掩蔽）**
  - **Gradient filtering（梯度算子）**

Lecture 4 – Frequency Domain Transform （频率域变换）

This lecture will cover:

– 2D Discrete Fourier Transform （傅里叶变换）

– Frequency Domain Filtering（频率域滤波）

- Lowpass Filtering（低通滤波器）
- Highpass Filtering （高通滤波器）
- Selective Filtering（选择性滤波）

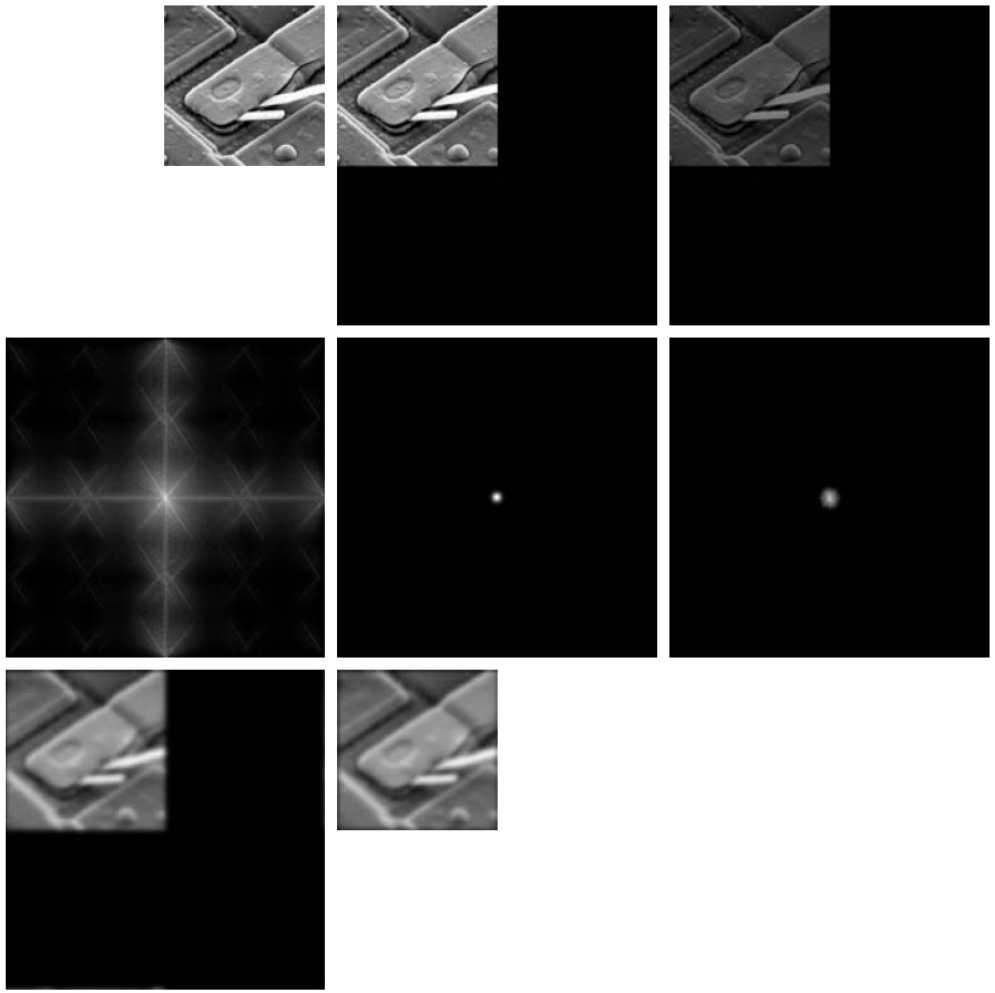
– Other Transform

- Discrete Cosine Transform（余弦变换）
- Walsh-Hadamard Transform
- Discrete Wavelet Transform （小波变换）

Properties of 2D DFT

- Spatial and frequency intervals （空间和频率间隔）
- Translation （平移）
- Periodicity（周期性）
- Rotation（旋转）
- Separability (可分性）
- Symmetry（对称性）
- Spectrum and Phase angle（频谱和相角）
- 2D Convolution theorem（卷积定理）

Steps of Frequency Domain Filtering



1. Zero-padding input image $f_p(x, y)$

2. $f_p(x, y)(-1)^{(x+y)}$ to center its transform

3. Compute DFT

4. $\boldsymbol{G}(u, v) = H(u, v)F(u, v)$

5. $\boldsymbol{g_p}(x, y) = Re[\mathcal{F}^{-1}[\big(G(u, v)\big)]]\ (-1)^{(x+y)}$

6. Obtain $g(x, y)$from top-left quadrant

Lowpass Filtering

- Ideal Lowpass Filter（理想低通滤波器）
- Butterworth Lowpass Filter（布特沃斯低通滤波器）
- Gaussian Lowpass Filter （高斯低通滤波器）

Lowpass filters. D_0 is the cutoff frequency and n is the order of the Butterworth filter.

Ideal	Butterworth	Gaussian
$H(u,v) = \begin{cases} 1 & \text{if } D(u,v) \le D_0 \\ 0 & \text{if } D(u,v) > D_0 \end{cases}$	$H(u,v) = \dfrac{1}{1 + [D(u,v)/D_0]^{2n}}$	$H(u,v) = e^{-D^2(u,v)/2D_0^2}$

Highpass Filtering

- **Ideal Highpass Filter（理想高通滤波器）**
- **Butterworth Highpass Filter（布特沃斯高通滤波器）**
- **Gaussian Highpass Filter （高斯高通滤波器）**

$$H_{\mathrm{HP}}(u,v) = 1 - H_{\mathrm{LP}}(u,v)$$

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Highpass Filtering

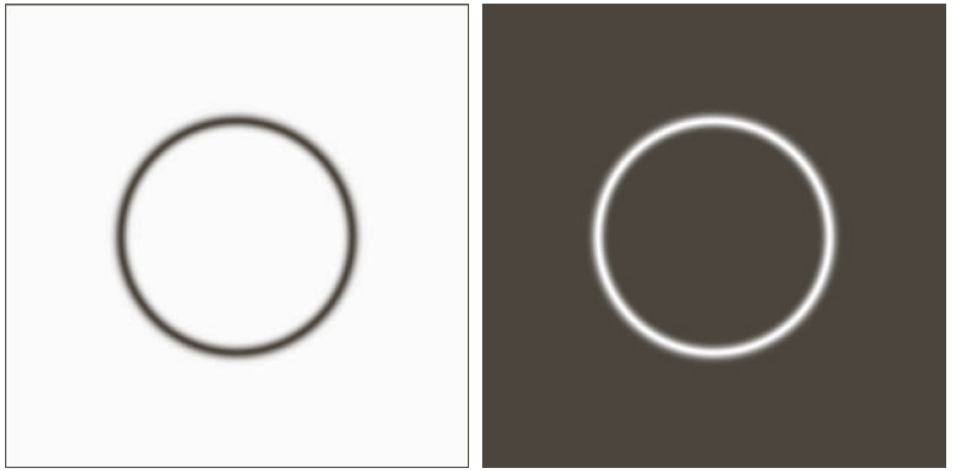
- Laplacian（拉普拉斯算子）
- Unsharp Mask（钝化模板）
- Homomorphic Filtering（同态滤波）

Selective Filtering

➢ Bandreject(带阻) and Bandpass(带通) Filters

$$H_{\mathrm{BP}}(u,v) = 1 - H_{\mathrm{BR}}(u,v)$$

Ideal	Butterworth	Gaussian
$H(u,v) = \begin{cases} 0 & \text{if } D_0 - \frac{W}{2} \le D \le D_0 + \frac{W}{2} \\ 1 & \text{otherwise} \end{cases}$	$H(u,v) = \frac{1}{1 + \left[\frac{DW}{D^2 - D_0^2}\right]^{2n}}$	$H(u,v) = 1 - e^{-\left[\frac{D^2 - D_0^2}{DW}\right]^2}$



Selective Filtering

- **Notch Filter** (陷波滤波器)
  - Reject or pass frequencies in predefined neighborhood
  - Symmetric about the origin for a zero-phase shift filters
  - Selectively modify local regions of the DFT

$$H_{\mathrm{NR}}(u,v) = \prod_{k=1}^{Q} H_k(u,v) H_{-k}(u,v)$$

$$H_{\mathrm{NP}}(u,v) = 1 - H_{\mathrm{NR}}(u,v)$$

Where $H_k(u,v)$, $H_{-k}(u,v)$ are Highpass filters with center at (u_k, v_k) and (u_{-k}, v_{-k})

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